May
1937

Electrical Engineering

Published Monthly by the American Institute of Electrical Engineers

Electrical Engineering

Registered U. S. Patent Office

for May 1937—

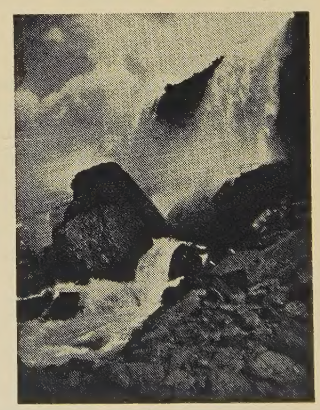
The President Meets the Sections	....A. M. MacCutcheon	...509
Engineering Progress and Economic Progress	....Harold G. Moulton	...510
Some Engineering Contributions to Society	....R. C. Muir	...518
Employment in the Engineering Profession		...524
Police Radio Communication	....Edwin Lee White and E. C. Denstaedt	...532
A New Approach to the Industrial Lighting Problem	....H. B. Dates	...545
Expulsion Protective Gaps	....W. J. Rudge, Jr. and E. J. Wade	...551
Empirical Method of Calculating Corona Loss From High-Voltage Transmission Lines	....Joseph S. Carroll and Mabel Macferran Rockwell	...558
Properties of Saturants for Paper-Insulated Cables	....G. M. L. Sommerman	...566
Distribution Lightning Arrester Performance Data	....Subcommittee Report	...576
Coincidental Electric Drives	....L. E. Miller	...578
Impulse Operation of Magnetic Contactors	....Carroll Stansbury	...583
A-C Motor Protection	....C. W. Kuhn	...589
Sixty-Cycle Calibration of the 50-Centimeter Ungrounded Sphere Gap	....C. S. Sprague and G. Gold	...594
Probable Outages of Shielded Transmission Lines	....S. K. Waldorf	...597

Discussion (See next page) 601

News 635

The Cover

Mighty Niagara, a point of interest for those attending the Institute's North Eastern District meeting in Buffalo, N. Y., May 4–6



©

VOLUME 56 NUMBER 5

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

High Lights

Summer Convention. Milwaukee and vicinity and the State of Wisconsin offer unusual opportunities to those wishing to combine attendance at the Institute's 1937 summer convention with their vacations. The program includes 10 technical sessions and one special "general" session. The usual sports competitions and a splendid array of interesting inspection trips and entertainment features provide a well-rounded program (*pages 635–9*).

Employment of Engineers. During the 5-year period from 1929 to 1934, the number of persons in the engineering profession increased by 25 per cent, which was much in excess of available engineering employment opportunities. This is one conclusion reached by the United States Bureau of Labor Statistics in analyzing the employment data obtained in its 1935 survey of the engineering profession (*pages 524–31*).

Some Engineering Contributions. In 1920, 41 million tons of coal was required to produce 27 billion kilowatt-hours of electric energy in power stations in the United States; in 1934 the same amount of fuel produced 57 billion kilowatt-hours. This is but one of the many engineering contributions to society which have resulted in providing the public with a dependable supply of electric power at low rates (*pages 518–23*).

Student Activities. Representative of activity of Student Branches throughout the Institute's various Districts, were the annual Student Branch conference of the Southern District (*pages 641–2*) and the annual convention of Student Branches in the eastern portion of the Middle Eastern District (*pages 640–1*), both of which were held recently.

Cable Saturants. Physical and electrical properties of several saturants for paper-insulated cables have been investigated in a series of tests, and correlations made with the viscosity index and chemical composition of the oils and resins. Gaseous ionization in insulation voids was found to exert pressure and accelerate oxidation (*pages 566–76*).

Lightning-Arrester Performance. From manufacturers' data pertaining to breakdown characteristics of lightning arresters under standard rates of voltage rise, and *IR* drops for crest values of current of 1,500, 3,000, and 5,000 amperes, the protective characteristics of 3- to 15-kv line-type arresters have been determined (*pages 576–77*).

Magnetic Contactors. Because of some fundamental limitations, the use of magnetic contactors as commutating devices for the application of power during brief periods has not been entirely satisfactory. A method of avoiding these limitations, and at the same time providing great accuracy of timing the periods of power application, has been evolved (*pages 583–8*).

Sphere-Gap Calibration. Much progress has been made in extending and revising the calibrations of the grounded sphere gap for both 60-cycle and impulse voltages. A paper in this issue presents some of these revisions, and, in addition, describes the effect of ultraviolet irradiation of the sphere gap (*pages 594–6*).

Expulsion Gaps. Guarding overhead power lines against damage from lightning by the use of expulsion protective gaps which conduct the lightning current to ground and break the power current that follows has been practiced for several years. Information obtained from field experience and tests is now available (*pages 551–7*).

Coincidental Electric Drives. Individual motors are used in some industrial applications to drive units of a machine that may require either a constant or a varying speed relation among the motors. Principles of operation are given in a general description of this type of drive (*pages 578–82*).

Economic and Engineering Progress. The development of the modern economic system has closely paralleled the growth of scientific knowledge, says a well-known authority in discussing progress in the interdependent fields of engineering and economics (*pages 510–17*).

Motor Protection. Thermal overload devices such as solder-film or bimetallic-strip relays commonly are used for the protection of a-c motors. Comparison of the proper motor and relay data provides a basis for the determination of adequate overload protection (*pages 589–93*).

Corona Loss. Most mathematical formulas for computing corona loss on transmission lines do not agree entirely with observed data for all conditions; therefore, a purely empirical method of computing corona loss has been derived from co-ordination of experimental observations (*pages 558–65*).

Outages on Shielded Lines. From the observation that flashover of transmission-line towers with 2 overhead ground wires occurs only when the product of tower-footing resistance and tower surge current exceeds the insulation strength, the probable outages may be determined (*pages 597–600*).

Police Radio. Law-enforcement agencies always are concerned with improving their methods of transmitting intelligence. In the last few years municipal and state police departments have turned to radio as the most rapid and effective means of dispatching patrol cars (*pages 532–44*).

Industrial Lighting. A broadening of the scientific knowledge of the relations of light to the process of seeing has suggested a new approach to the specification of lighting for industrial processes (*pages 545–50*).

Year Book. The Institute's 1937 Year Book is now available to members having use for it (*page 641*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

Electrical Machinery

Abrasion—A Factor in Electrical Brush Wear—Hessler 601
Arc Characteristics Applying to Flashing on Commutators—Hellmund 603
Contact Drop and Wear of Sliding Contacts—Baker & Hewitt 605
Self-Regulated Compounded Rectifiers—Goodhue & Power 606
An Analysis of the Shaded-Pole Motor—Trickey 612
Induction Motors on Unbalanced Voltages—Reed & Koopman 621
Capacitor Motors With Windings Not in Quadrature—Puchstein & Lloyd 634

Electrophysics

Expansion Theorems for Ladder Networks—Malti 601

Power Transmission

Lightning Investigation on a 220-Kv System—II—Bell 622
Lightning Investigation on Transmission Lines—VI—Lewis & Foust 624
Electrical Characteristics of Suspension-Insulator Units—Dawes and Reiter 628
Lightning Protection for Transmission Lines—Gothberg & Brookes 631
First Report of Power System Stability—Subcommittee Report 632

Tensor Analysis

Dyadic Algebra Applied to 3-Phase Circuits—Sah 610
Complex Vectors in 3-Phase Circuits—Sah . . 610
The Tensor—A New Engineering Tool—Boyajian 614
Tensor Algebra in Transformer Circuits—Bewley 614
Tensor Analysis of Multielectrode-Tube Circuits—Kron. 614

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index;* abstracted monthly by *Science Abstracts* (London).

Number of copies this issue—20,200.

Electrical Engineering

Published Monthly by

American Institute of Electrical Engineers

FOUNDED 1884

VOLUME 56, NO. 5 ▼ ▼ ▼ **MAY 1937**

The President Meets the Sections

"ON what subject would you like a message from the president?" I asked 2 young engineers who have recently joined the AIEE. Their answer was, "Tell us about the work of the other Sections." So I was led to review my pleasant travels of the last 9 months, and the many Sections I have been privileged to visit.

Why does the president visit the Sections? Primarily because they invite him to do so; and it is his pleasure and duty, as far as possible, to accept these invitations from those who have elected him. It is certain that these visits inspire him and acquaint him with the activities and needs of the organization. It is hoped that from him each Section visited learns of national affairs, of the work of the other Sections, of projected policies, and from him receives some degree of inspiration, leading to greater Section activity.

The courtesy, hospitality, and interest shown by every Section visited, have made this phase of my Institute activity one which I long shall remember. In the last 9 months, I have visited 33 Sections and 18 Branches, and attended 2 conventions and a District meeting. In the next 4 months, I shall visit 11 Sections and 4 Branches, and attend a District meeting, a District student convention, and a national convention. While visits to Sections are desirable, inspiring to the President and, I hope, to the Sections, visits to Branches I consider even more desirable, for within the Branches are found the engineering leaders of the future.

Last November I told you something of my early trips and my pleasure in attending the twin meetings at Knoxville and Chattanooga, which initiated the active participation of the East Tennessee Section in Institute affairs. October and November were marked by a Western trip, with meetings at St. Louis and Kansas City, Mo., on the way to the South West District meeting at Dallas, Texas. The automobile drive from Kansas City to Dallas, with E. T. Mahood, past chairman of the Kansas City Section, and Mrs. Mahood, familiarized me with the great Southwest, and permitted a preliminary social visit with the officials of the Oklahoma City Section. Reviewing the 3-day Dallas meeting, I was indeed surprised that 6 of the 9 meals were in the company of Vice-President L. T. Blaisdell. This same vice-president accompanied me to the Houston Section meeting and, returning with me to Dallas, drove me to the Oklahoma Section meeting approximately 350 miles away. The following morning I inspected the Oklahoma oil field and saw a 110-horsepower motor, 10 inches in diameter and 20 feet long. Guided by the proverb "all work and no play," the afternoon was devoted to golf.

In quick succession followed enthusiastic Section meetings at Salt Lake City and Denver, with Branch meetings at the Universities of Colorado and Utah.

Stealing a Sunday en route from Denver to Los Angeles, I realized a 40-year-old ambition: a trip to the bottom of the Grand Canyon on mule back. It is highly recommended. In Los Angeles a noonday meeting with the Section executive committee preceded a joint meeting with the technical societies of Los Angeles, addressed by Dr. Von Kleinschmid, president of the University of Southern California, and myself. I strongly favor these joint meetings with other engineering societies.

A plane trip to San Francisco made possible a Branch meeting at the University of California, with a Section meeting the following evening. Then came Portland, Seattle, Vancouver, Spokane, with Branch meetings at Washington State College and the University of Idaho. At Bozeman, there was a meeting of the Montana State College Branch at 11:00 a.m., luncheon with the faculty, and a Montana Section meeting in the evening. The following day another lifetime ambition was realized. Professor J. A. Thaler and his delightful wife drove me to Yellowstone Park. Over a railroad electrically operated through its mountain divisions, I reached Milwaukee, Wis., and was entertained at lunch by the entire 1937 summer convention committee. In the evening was the joint Milwaukee-Madison Section meeting at the Allis-Chalmers Club. (Do not miss the Milwaukee convention this June.)

The trip back to Cleveland was enlivened by a luncheon with the Chicago Section executive committee, and attendance at the regular Chicago Section dinner meeting where, fortunately, I had the opportunity of hearing another speaker.

Participation in Section meetings at the neighboring cities of Pittsburgh and Erie, Pa., was easily accomplished.

Going to the New York winter convention by the way of a Toronto Section dinner meeting was a most pleasant experience, and approaching Miami, Fla., by the way of a Caribbean cruise was equally delightful. (See message in March issue.)

Such an extensive Section as Florida required 2 meetings, at Miami and Jacksonville, one of which unfortunately was missed because weather conditions prevented the scheduled sailing of a plane.

The best method of transportation through Florida was found to be by the use of a Ford car rented in Miami and delivered at Jacksonville; a stop was made at Gainesville for a meeting of the University of Florida Branch and a radiobroadcast.

By a zigzag route and close co-operation from Institute members, we attended an all-afternoon Section meeting at Raleigh, N. C., a pre-organization meeting at Columbia, S. C., visited the Broad River power development, met with the Branches at Clemson College, Georgia School of Technology, Alabama Polytechnic Institute, and the University of Alabama, and addressed the Atlanta and Alabama Sections at enthusiastic dinner meetings. National Secretary Henline joined me at Raleigh, and ably participated in all the meetings that followed.

The March trip through New England was distinctive. It was completely arranged by Vice-President A. C. Stevens and District Secretary R. G. Lorraine. They, with Mr. Henline and myself, made up an official visiting delegation. Through their efficient organizing, we were able to attend 6 Section meetings in 5 days: Connecticut, Lynn, Boston, Providence, Worcester, and Springfield. Three of these were joint Branch-Section meetings. This was one of the most inspiring trips of the year.

Ahead of me is the privilege of attending the meeting of the North Eastern District at Buffalo, N. Y., the Student Branch convention of the North Central District at Brookings, S. D., the Milwaukee national convention, as well as visiting the following Sections: Chicago, Philadelphia, Sharon, Baltimore, Minneapolis, Cincinnati, Rochester, Ithaca, and Lehigh Valley. Last, but not least, is the annual meeting of my own Section, to be held in Cleveland on May 20.

This is the story of my travels, and the roster of the Sections and Branches with which I have been fortunate to become acquainted. Next month I shall take the opportunity of telling you what I learned of these Sections and Branches, their activities, and their plans for the future. I hope that each Section and Branch may receive help and inspiration from the record of what the other Sections and Branches are doing.

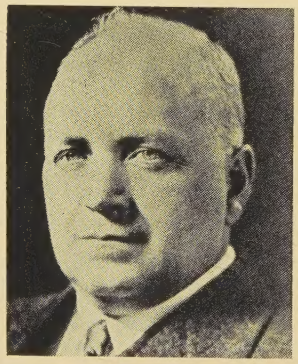
A M MacCutcheon

Engineering Progress and Economic Progress

By HAROLD G. MOULTON
President, The Brookings Institution

The advance of engineering has a vital bearing upon economic progress; in turn, though perhaps less obviously, the operation of the economic system largely determines the rate at which new engineering discoveries may be applied in the actual production of wealth. From this point of view Doctor Moulton discussed progress in the interdependent fields of engineering and economics in the Eleventh Steinmetz Memorial Lecture,* full text of which is presented here.

ENGINEERING is concerned with the application of scientific knowledge to the processes of wealth production. Economics is concerned with the basic resources and factors upon which wealth production depends and with the forces and institutions that influence or control the operation of what we call the economic system. It is readily apparent, therefore, that the advance of engineering has a vital bearing upon economic progress. In turn, though perhaps less obviously, the operation of the economic system largely determines the rate at which new engineering discoveries may be applied in the actual production of wealth. This truth is brought sharply to our attention in periods of acute business depression, when the introduction of improvements of demonstrated value is indefinitely deferred, and the process of discovery and invention itself is slowed down; but even in times of prosperity the installation of new methods and devices is not infrequently retarded because of general economic considerations.



In view of this intimate relationship between engineering and economics, it affords me especial pleasure to join with you in considering problems of mutual interest on a forum dedicated to the memory of a great scientist and engineer, who was at the same time deeply concerned with the relationship of his profession to the development of civilization.

Science and Economic Development

The development of the modern economic system has in fact closely paralleled the growth of scientific knowledge. By way of introduction, let me briefly recapitulate the history of the last 3 centuries in terms of engineering and economics. Though not commonly realized, developments in the field of the so-called natural sciences paved the way for the modern political and economic system.

It was in the sixteenth and seventeenth centuries that such men as Galileo, Kepler, and Newton discovered and formulated the basic laws that operate in the physical world. In due course these scientific discoveries came to exert a profound influence upon men's ideas in other realms of thought. Was not man, the creation of God, as much a part of and subject to an ordered universe as the physical earth on which he had his setting?

The view arose that there existed a system of *natural law* which, if it were not interferred with by governments or other human institutions, would always lead to progress. Blackstone, the great English jurist, for example, contended that there had been established by the Creator a simple system of natural law or ethics, and that the constitution and frame of humanity had been so contrived that if we but pursued our own "true and substantial happiness" we could not fail to be in tune with the universe of nature. Moreover, according to Adam Smith, the great Scottish philosopher who founded a system of thought known as political economy, each of us in pursuing his own welfare and happiness is led as by the Divine Hand to promote the welfare of his fellowmen.

This new philosophy of *natural law* led in due course to practical results of great significance. First, innumerable laws restricting the freedom and the initiative of the individual were repealed. Second, industry and trade were relieved from a multitude of hampering regulations. Third, national boundaries came largely to be ignored through the removal of barriers and restrictions against the free international movement of trade and currency, and against the migration of people from country to country. The conception of a world society was born, in which men should be free not only to develop their individual capacities to the utmost, but also to live in whatever spot on the globe they desired and to conduct their business operations without reference to any national boundaries.

All this, it may be seen, constituted a *theory* of economic and social evolution or a *science of society*. New conceptions resulting from discoveries in the field of natural science came in time to be the foundations of social science. Moreover, the practical application of scientific discoveries

* Eleventh Steinmetz Memorial Lecture delivered by Doctor Moulton under auspices of the Steinmetz Memorial Foundation at a meeting of the AIEE Schenectady, N. Y., Section on April 6, 1937.

HAROLD G. MOULTON received the degree of doctor of philosophy from the University of Chicago in 1914, and was a member of the faculty until 1922. At that time he resigned the post of professor of political economy to become director of the Institute of Economics, Washington, D. C. The institute was amalgamated with the Institute for Government Research and the Robert Brookings Graduate School of Economics and Government in 1927, and Doctor Moulton was appointed president of the newly formed Brookings Institution. He is the author of many books on economic and allied subjects.

to the processes of production gave to the business organizer an ever expanding scope for his enterprise. One need cite only the influence of steam, electric, and gasoline power on transportation development to indicate the significance of science in broadening the area over which business enterprise can successfully operate.

Rising Standards of Living

In the short interval of time since the founding of the American Republic, man's power over nature has been increased vastly more than in all preceding history. If we were to let the span of human history be represented on the face of a clock, the period elapsing up to the last 2 centuries would be roughly the equivalent of the time from noon to 10 minutes before 12 midnight. The last 10 minutes would represent the period during which science, engineering, and the system of free business enterprise have been dominant. Economic progress during these last 10 minutes has greatly exceeded that of the preceding 710 minutes. The standards of living of the masses today, notwithstanding an extraordinary increase in population, are higher than those of the classes of former times.

Statistical measurements as to the rate of economic progress are available only for comparatively recent years. But in the era of expansion from 1900 to 1929 production per capita in the United States increased by about 38 per cent; and there was a 13-per cent shortening of the hours of labor. In manufacturing industry the increase in efficiency was, of course, much greater. In the 7-year period from 1922 to 1929 efficiency in manufacturing increased by 25 per cent.

Retardation of Economic Growth

Despite the remarkable developments that have occurred under the capitalistic system, no one who thoughtfully surveys the economic history of recent times can well be complacent. Not only do we have periodic depressions which destroy accumulated wealth and income; but even at best the performance of the economic system leaves something to be desired. It would seem, when one stops to think carefully about it, that the rate of economic progress ought to be a constantly accelerating one—since each new generation starts with larger margins above the requirements for subsistence and builds upon greater accumulations of scientific knowledge and experience. Certain observed tendencies, however, are disquieting. Apart from the long periods of business depression and stagnation, one notes that the older and more mature a nation becomes the less rapid seems to be the rate of economic progress. In any event, the question sharply presents itself: Do conditions develop in the operation of the economic system which seriously retard further applications of engineering knowledge, and hence further progress?

It has been with a view to throwing light upon this basic question that the Brookings Institution in recent years has carried through a series of investigations under the broad general title of the distribution of income in relation to economic progress. Some of the results of these studies are here brought to your attention by means of a series of charts.

Before presenting these charts let me briefly recapitulate some of the conclusions reached.

1. It was found that there is a substantial margin of unused productive capacity, even in periods of prosperity. In the boom period, 1925–29, the economic system as a whole was not producing at more than 80 per cent of capacity; we did produce about 81 billion dollars worth of goods and services in 1929, but we might have produced about 96 billions.

2. The failure to use all of our productive capacity could not be attributed to an existing excess of production as compared with human needs. Production in the United States in 1929 amounted to only about $660 per person—about $2,600 per family. It would have required a vast increase in output to provide reasonably satisfactory standards of living for the American people.

3. The failure to produce more was attributable to an inability to find markets adequate to absorb full productive capacity.

4. The lack of adequate markets reflected inadequate purchasing power on the part of the masses of the people having large unfulfilled desires.

5. The inability of the masses to buy larger quantities was a result of the discrepancy between their money incomes and the prices at which goods were offered in the markets.

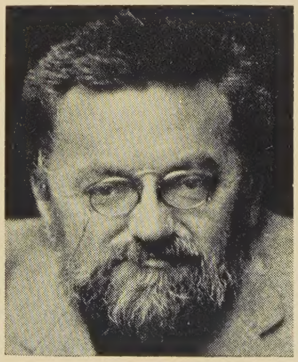
This last point will be developed at some length in the course of the discussion, but first let us have a brief look at the charts that bear upon the conclusions just stated (figures 1 to 9, inclusive).

Effects of the World Depression

Figures 1 to 5 relate chiefly to the predepression situation and are concerned solely with the United States

---

THE Steinmetz Memorial Lectures were established in 1925 by the Schenectady Section of the AIEE, as a means of recalling periodically to the members of the Section and the general public the personality and achievements of Charles Proteus Steinmetz. The interest aroused by these lectures has been such that his friends and admirers have raised an endowment fund to place the memorial on a permanent basis, independent of the future success of the Schenectady



Section of the AIEE. This fund will insure that the memory of Doctor Steinmetz will be recalled frequently in a way most appropriate to commemorate a man who combined a lovable personality and a broad human interest with the highest grade of scientific attainment. Previous lectures have been delivered by M. I. Pupin, E. J. Berg, R. A. Millikan, Max Mason, D. S. Kimball, W. E. Wickenden, K. T. Compton, C. E. K. Mees, R. E. Doherty, and Gerard Swope.

The next series of charts (figures 6 to 8) is focussed directly on the effects of the depression upon economic progress both in the United States and the world at large.

All the diagrams thus far mentioned fail to portray fully the effects of the depression because the factor of general growth is not included. With the population of the United States in 1936 about 5 per cent greater than in 1929—indeed with the population of working age about 9 per cent greater—we should expect a proportionally larger output than in 1929. In fact, had it not been for the depression we might have expected the supply of capital and the efficiency of production to continue at something like its usual rate of increase, with a corresponding expansion in per capita output. The next chart (figure 9) indicates in a rough way the effects of the depression by comparing actual production since 1929 with the amount of production that we would have had if predepression trends had been continued.

Figure 9 shows that in 1936 the average production (including agricultural and mineral as well as manufacturing) should have been about 20 per cent higher than in 1929; in fact, it was less than 90 per cent of the 1929 level. In other words, the output was not quite $^3/_4$ as great as it would have been had there been no interruption to progress.

The results of this curtailment of production are of course clearly revealed in the statistics of national income.

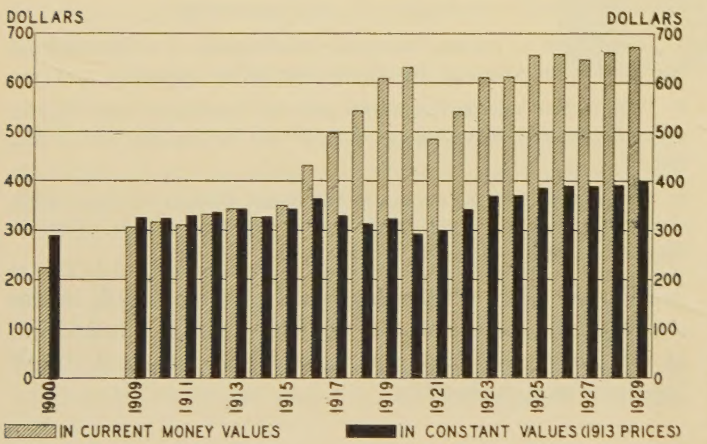


Fig. 1. Per-capita income from current production

This diagram reveals the growth of national income over the 30-year period of expansion from 1900 to 1929. As already stated, the increase amounted to about 38 per cent per capita, while at the same time there was a 13-per cent reduction in working hours. The cross-hatched bars indicate the amount of income as measured in actual dollars. The dark ones indicate the amount when adjustment is made for the fluctuations in commodity prices. It is of course the latter that represent the real growth in income

Had there been no depression and had the prewar trend of production continued, the total national income in 1936 would have been more than 97 billion dollars (as measured by 1929 prices). The actual income in 1936, including that received by individuals engaged in work relief, was only about 70 billions (again as measured by 1929 prices).

Engineering and Economic Fundamentals

In the light of these graphic illustrations of economic retardation, we may now return to the discussion of engineering progress and economic progress. We shall center our attention not so much upon the phenomenon of the depression itself as upon the longer-run persistent factors or tendencies that affect the rate of progress.

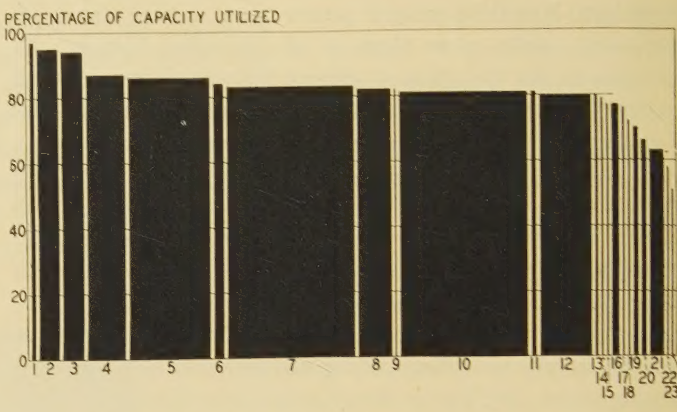


Fig. 2. Utilization of mineral capacity

This diagram indicates the percentage of capacity that was actually utilized in the various divisions of the mineral industries in 1929. Each bar represents a particular division of the industry, the width indicating roughly its relative importance. The highest degree of utilization is found in electrolytic copper refineries and the lowest in black powder mills. It may be observed that in the main the utilization was in the neighborhood of 80 per cent. The large area labeled 5 is petroleum refineries; 7 is bituminous coal mines; 10, crude oil; and 12, anthracite collieries

The engineering attitude always has been direct and fundamentally simple. Moreover, its validity is not open to challenge. It is based upon the elementary assumption that the function of engineering is to apply the new knowledge that is continuously accumulating to the improvement of productive instruments and processes, with a view to increasing the efficiency of mankind in adapting natural resources to the satisfaction of human wants. Increasing efficiency simply means producing more with the same effort—in consequence of which standards of living will be raised.

If it be agreed that the engineering conception of progress is indubitably true, then it must follow that the test of an economic system is to be gauged by its efficiency in promoting the engineering ideal. The system of private business enterprise, as it has often been expounded by both professional economists and business leaders, does in fact embody this engineering conception of progress. The nature of the problem is complicated, however, by the fact that under the capitalistic system production is financially organized and controlled.

Business managers use money in the hiring of labor and

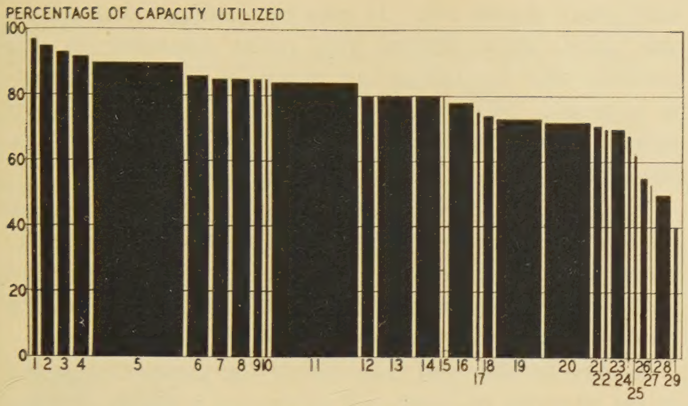


Fig. 3. Utilization of manufacturing capacity

This shows the degree to which manufacturing capacity was utilized on the average in the 5-year period from 1925 to 1929. A somewhat wider range is indicated here, but again the general average is not far from 80 per cent. The highest degree of utilization is in full-fashioned hosiery establishments, and the lowest in locomotive plants. The large area, 5, is printing and publishing; 11 is automobiles; 13, cotton manufactures; 14, boots and shoes; 16, men's clothing; 19, rolled-steel products; and 20, lumber

in the purchase of materials and supplies, and they sell their products for money. The aggregate amount of money received from sales of course must exceed the aggregate disbursements if profits are to be realized. Thus, business has its setting in a structure of monetary costs, prices, and profits; and the economic requirements for progress must accordingly be analyzed in these terms. The incentives and mechanisms by which the competitive system has been supposed to insure rapid economic progress and higher standards of living may be summarized briefly as follows:

1. It is contended that each business manager naturally stands to gain by increasing efficiency and thereby reducing costs. He may accomplish this by the construction of a larger and more efficient plant, by the installation of better equipment, by the introduction of superior internal management, by improved methods of marketing, by integrating various stages in the productive process, or by a combination of various methods.

2. Having reduced costs of production he is in a position to increase his profits in one or another of 2 ways: He may continue to sell at the same price as before, enjoying the advantage of a wider margin between cost and selling price, or he may expand the volume of his business by means of price concessions. It was reasoned that since the increase in efficiency which is responsible for the reduction in costs commonly involved an expansion of productive capacity, and since the maximum economies can be obtained when operating at full capacity, the greatest profits will result if sales are expanded by means of a reduction of prices. In short, increased efficiency makes possible lower prices, while the profit incentive was held to insure an actual reduction of prices.

3. The process naturally involves the continuous elimination of obsolescent or otherwise inefficient high-cost establishments. The industrially fit, as gauged by ability to sell at a minimum price, alone survive; moreover, the efficient of today promptly become the inefficient of tomorrow. A particular business man, firm, or corporation may indeed survive over a long period of years, but only if the production methods employed keep always abreast of changing times. It may be seen that with the system thus operating, standards of living would steadily rise. The progressive reduction of prices as efficiency increases would, of course, constantly increase the purchasing power of the masses—giving them an increasing volume of goods for the same money.

It should be carefully noted that this theory of progress implies that the reduction in money costs must result

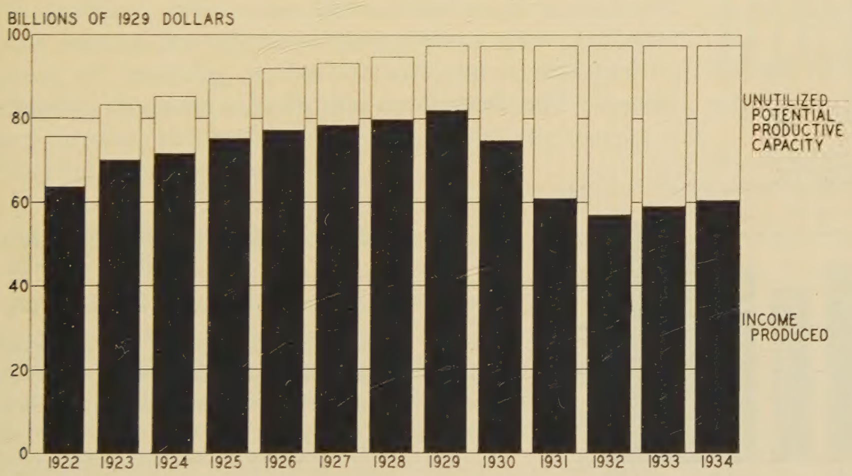


Fig. 4. Productive capacity and actual production

Here is a rough picture of the economic loss to the nation over a period of years resulting from our failure to make full use of our productive capacity. The black portions of the bars show the actual income produced in the years 1922 to 1934, inclusive. The upper areas indicate the additional amounts that might have been produced had our resources been fully utilized. For lack of adequate data as to the growth of productive capacity after 1929, the height of the bars has not been extended above the 1929 level. Since in the absence of depression productive capacity would have continued to expand, the diagram materially understates the true situation. A later diagram (figure 9) serves to reveal the indirect losses resulting from the depression

Fig. 5. Fluctuations in production of consumer and capital goods

The most striking result of a depression is the extraordinary decline in the rate of construction of new plant and equipment. That is to say, the application of scientific and engineering knowledge to the further expansion of productive capital is seriously impeded. This diagram shows that the amount of new capital construction at the depth of the depression in 1933 was only 40 per cent of that in 1929, being confined almost entirely to replacement as distinguished from new capital construction. Even after 3 years of recovery the rate of capital construction is still far below predepression levels

from increased efficiency rather than from a mere reduction in money wage rates. A reduction in wage rates may indeed lower money costs and prices; but since it neither increases efficiency nor the purchasing power of the masses there is no resulting economic advancement.

In order to reveal more distinctly what is involved in raising living standards in a *pecuniary* society, I would lay down 2 principles as follows:

1. *The process of raising the standard of living of wage earners necessarily involves increasing the spread between wage rates and prices.* That is, a wage earner can increase the volume of his purchases from year to year only if wage rates are increased relative to the prices of the commodities he buys. If he gets more dollars and prices remain unchanged, his purchasing power is expanded; if he gets the same number of dollars and prices decline, his purchasing power is expanded. It cannot be expanded, however, unless the spread between wages and prices is increased.
2. *An increasing spread between wage rates and prices depends fundamentally upon increasing the efficiency of production.* While minor and temporary increases in wages sometimes may be achieved by trenching upon profits, a progressive increase in the wage-to-price ratio depends directly upon the acceleration of technical advancement, improved management, increased labor efficiency, etc. Any practices or policies that tend to work in this direction are economically sound; any that work in the opposite direction are economically unsound.

We may now leave for a moment the discussion of principles and requirements and turn again to the factual record. The great increase in living standards over the past 200 years to which reference has been made has been brought about by increasing efficiency and an increasing spread between wage rates and prices. The statistics of wages and prices indicate that at certain periods increased purchasing power has resulted mainly from wage increases and at other periods mainly from price reductions. Sometimes also improvements in living standards have come about simply by the process of a more rapid rise in wages than in prices.

The trend of wholesale prices in relation to weekly wages over the period from 1800 to 1930 is shown by the next chart (figure 10). It may be observed that wholesale prices show several high peaks occurring in war periods, with fluctuating but generally downward trends in between. Money wages, however, show a persistent upward trend over the period as a whole. In consequence, the general trend of real wages is sharply upward.

For recent years data with respect to wages and prices are more detailed and precise. The next chart (figure 11) shows hourly earnings in manufacturing industries and both wholesale and retail prices of finished manufacturing products for the 15-year period 1932 to 1936.

It may be observed that during the prosperity period of the twenties wholesale prices showed a slight irregular decline, while retail prices remained practically stationery. Hourly earnings increased sharply in 1923 but very moderately thereafter. Real wages, however, did not increase as fast as productive efficiency.

During the course of the depression hourly earnings fell somewhat less rapidly than either wholesale or retail prices. Since the beginning of the recovery period hourly earnings have risen much more than either wholesale or retail prices. In fact, hourly earnings at the end of 1936 were actually above the 1929 level, whereas prices were nearly 20 per cent below.

In concluding this discussion it should be noted again that the benefits of technological advancement may be disseminated *either* by increasing money wages or by decreasing prices. Which of these alternative means is the more effective?

The answer is decreasing prices. The wage increase method enhances the purchasing power of only that portion of the population which works for wages—and this constitutes only about 40 per cent of the entire population. When prices are reduced, on the other hand, everybody is benefited; wage earners, salaried employees, farmers, and professional groups alike are able to get more for their money. This method not only gives a maximum increase

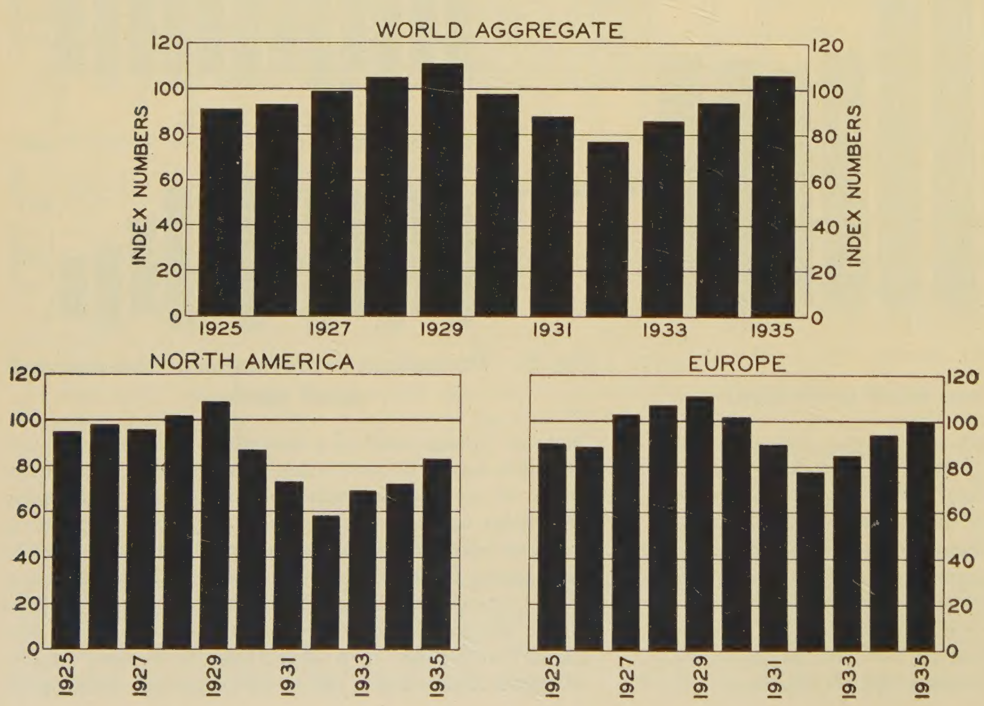


Fig. 6. World manufacturing activity, 1925–35

(1925–29 average = 100)

It may be observed that the aggregate volume of manufacturing in the world at large was steadily expanding from 1925 to 1929; that during the next 3 years it fell precipitately, reaching a level substantially below that of predepression years; and that after 3 years of recovery we were still below the level of 1929. Data for the year 1936 are not yet available, but it is probable that the total for that year will be slightly above that for 1929. It should be borne in mind in this connection, however, that world population has meanwhile increased by at least 6 per cent. It will be noted also that the decline was appreciably greater in North America than in Europe and that the degree of recovery has been somewhat less

in purchasing power, but it also serves to maintain a better balance between different divisions of our economic system, particularly between industry and agriculture.

It does not follow, however, from the indubitable fact that the broadest possible dissemination of income is attained through reductions of prices, that this method must be given sole consideration. Psychological and other practical factors may also warrant wage advances. Profit sharing also may have an important rôle to play. It may be concluded, however, that price reductions—because of the universal character of their effects—should constitute the primary means of disseminating the benefits of technological improvements.*

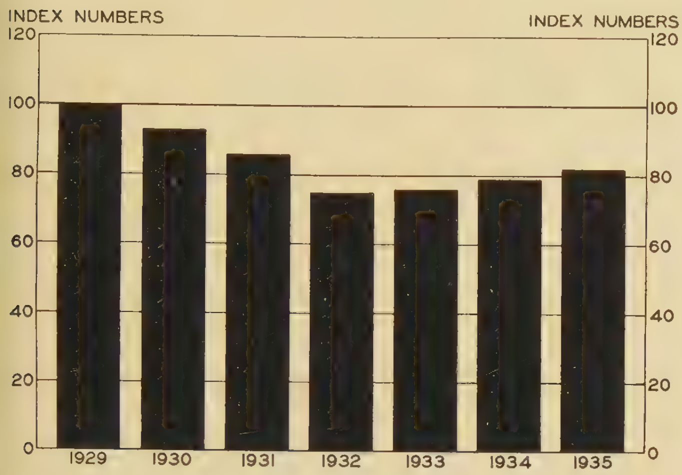


Fig. 7. Volume of world trade

The volume of world trade declined from 100 in 1929 to 75 in 1932. In 1935 it had returned to only 82 per cent of the 1929 level, and there was only a moderate increase in 1936. Exchange depreciation and controls, tariffs, and other commercial restrictions, and the drying up of international credit, have served to prevent any material recovery in international trade

Price Restriction Policies

From the preceding discussion of the operation of the economic system and the progressive rise in standards of living, it would almost seem that the operation of the economic system is highly satisfactory. But such a conclusion is obviously not warranted in the light of the earlier discussion of the ineffective utilization of productive capacity. The truth of the matter is that the price mechanism of increasing purchasing power does not always freely operate.

Over the last 50 years interferences have been developing to the free functioning of the price mechanism. Instead of reducing prices as a means of expanding markets, there has been a growing tendency to maintain prices and to let well enough alone.

Interferences with competitive price movements have occurred as a result of the development of at least 3 major types of business organization. The first is the unified monopoly or industrial combination under single management. The second, found chiefly in Europe, is the cartel or "collective monopoly" under which there is group control of production with a view to stabilizing prices in a given industry. The third is the trade association which seeks, usually through informal co-operation, to stabilize certain conditions within particular industries without interfering with the control of production. There are, of course, many different types of trade associations, and not all are able to exert an influence upon prices; but, by and large, trade associations consciously or unconsciously promote price stability. These associations, unlike consolidations, have generally been viewed with favor by the United States government as a means of stabilizing business.

The results of these policies have been most clearly manifested in the decade of the twenties. This was a period of remarkable advancement. Both the amount of capital and the efficiency of its use increased in nearly all lines of production. In manufacturing industry generally the increase in efficiency was something like 25 per cent. But the benefits of this increasing efficiency were not automatically passed on to the masses of consumers either through the medium of proportional wage increases or proportional price reductions. Wholesale prices of manufactured commodities declined a scant 5 per cent and retail prices did not decline at all. The rate of profits showed a considerable increase during these years. During the recovery period from the beginning of 1934 until the last quarter of 1936 the wage-price mechanism appeared to be working in a very satisfactory manner. As has already been revealed, prices of manufactured goods

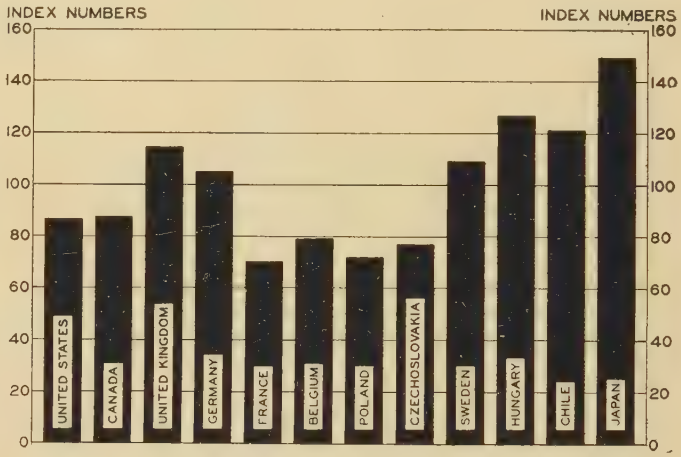


Fig. 8. Industrial production in selected countries

In this diagram the output in the year 1929 is taken as 100. Several of the countries included, notably Japan, Hungary, Chile, and the United Kingdom, show production in June 1936 at a level substantially above that of 1929. The United States and Canada stand in an intermediate position, at about 85 per cent, while France, Belgium, Poland, and Czechoslovakia lag materially

* In this brief summary statement only the high points of the analysis can be given. The interested reader may find the full appraisal with supporting data in 4 volumes published by the Brookings Institution under the titles "America's Capacity to Produce"; "America's Capacity to Consume"; "The Formation of Capital"; and "Income and Economic Progress."

fell somewhat, while hourly earnings rose materially. The result was a substantial increase in the wage-to-price ratio. Since this improvement in the wage-to-price ratio was matched by a more or less corresponding increase in efficiency, profits were not reduced. On the contrary, the fuller utilization of capacity that came with an expansion in the total volume of business served to increase the net income of corporations.

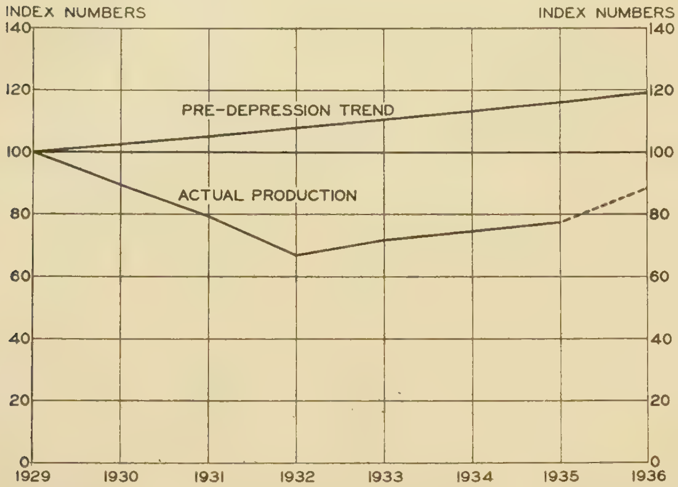


Fig. 9. Actual production compared with predepression trends

The upper line is an extension of the predepression trends of production from 1929 to the end of 1936. The lower line shows the actual production, the figures for 1936 being estimated as shown by the dotted projection of the line

Current Trends

At the end of 1936 the economic situation appeared in many ways exceptionally favorable. Production was steadily increasing, purchasing power was being broadly disseminated among the masses, speculative business activity was not in evidence, inventories remained low, and the general balance between production and consumption was satisfactory. Moreover, there existed clearly defined production requirements adequate, as some studies have shown,* to absorb all the unemployed.

In recent months, particularly since February, the situation has changed in one vitally important respect. Not only have prices of raw materials been rising, but we have had sharp increases in wage rates. These wage increases, ranging from 20 to upward of 30 per cent, have not been related to increases in efficiency. Partly because of this fact, but also in part because of shortsighted industrial policy, the prices of manufactured products are being rapidly advanced. While it is too early to make reliable comparisons of the precise degree to which wages and prices respectively have advanced, there is apparently a strong disposition to assume that prices must be raised in at least equal proportion to the wage advances. The requirement obviously is to restrain the price increases just as much as possible, in order that purchasing power may not be undermined.

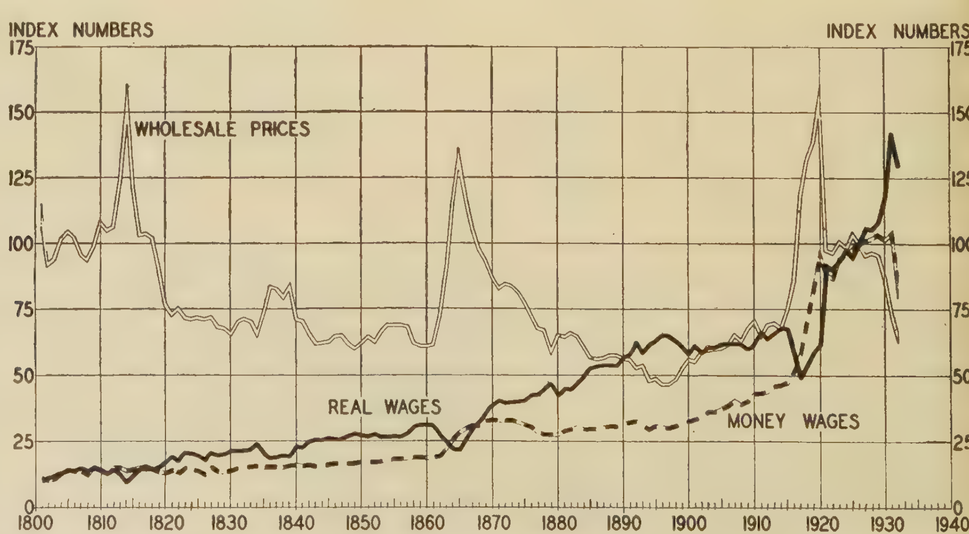
The possible effects of the sharp increases in wages and industrial prices must be viewed with apprehension, for they are laying the basis for an old-time vicious spiral of inflation. Rising costs lead to rising prices, and higher prices in turn lead to further advances in wages, costs, and prices. Moreover, a new maladjustment disruptive of balanced relationships is being introduced into the economic situation. While the particular labor groups that receive higher wages may stand to gain for a time, and while the industries in question may temporarily pass on the higher costs to consumers, further extensive expansion appears to be threatened.

The advance in the prices of such basic products as iron and steel and other metals, and building materials, may well serve as a direct impediment to the expansion of production in certain very important lines. The financial condition of the railroads has only recently improved sufficiently to permit extensive physical reconstruction of properties; but now with the prices of steel rising rapidly and railway wage increases also in immediate prospect, it

* See "The Recovery Problem in the United States," published by the Brookings Institution.

Fig. 10. Movement of wholesale prices and weekly wages

The upper line indicates the movement of wholesale prices; the lower one the movement of money wages; and the middle the trend of *real wages* as measured by the relation of prices to wages



is doubtful whether the railroads will be able to carry out the comprehensive programs of rehabilitation that have been prepared. Similarly, the building of new houses, apartments, and other structures may well be held in check by the rising prices of building materials. If this happens, the recent trends will have served to prevent the absorption of the unemployed and the attainment of the higher standards of living which are so greatly desired.

It may be noted also that large sections of the population would soon suffer as a result of a rapid rise in prices, such as: (1) the farmers who do not work for wages; (2) individuals who are working for fixed salaries; and (3) those living on incomes from investments. All these number more than 50 per cent of the total population. Perhaps the most serious phase of the problem relates to the disparity that may again result between industrial and agricultural prices. This is one of the reasons why the government has become so seriously concerned over recent developments.

Temporary Stimulating Effects

One must note, however, that the adverse effects upon production may be considerably delayed. This is because a rise in prices usually provides an immediate stimulus to industrial activity. With prices going up, business men and others hasten to place orders and buy extra quantities in order to be ahead of the price advance. This expansion of orders accelerates business activity and for a time increases the demand for labor. This expansion of demand in turn serves to increase the demand for products and to raise prices more rapidly. In due course, however, this process serves to intensify the disturbance in price relationships in the different parts of the economic system.

Profits that result from increasing efficiency and an expansion in the total volume of business are soundly based, but profits derived merely from advancing prices are not. Rising prices may indeed stimulate an increase in production and bring on an industrial boom; but since the buoyant activity that results merely from price increases is not accompanied by a corresponding expansion in the purchasing power of the masses, it is not self-sustaining.

It should be clear even from this brief and inadequate analysis of the factors and forces involved in the operation of the economic system that we cannot hope to have economic progress commensurate with the potentialities opened up by modern science and engineering unless governmental, industrial, and labor policies alike are based upon knowledge and understanding of economic fundamentals. The paramount need is for the development and adoption of policies that will promote ever increasing efficiency and ever rising standards of living.

Instead of having reached the limit of progress under the capitalistic system, we should be merely on the threshold of economic advancement. Building on the economic accumulations of the past and on the foundations of modern science, we should be able to look forward to a rate of economic progress in the future that would dwarf anything known in the past. The problem is simply one of the recognition of certain fundamental requirements and the operation of the economic—and political—system in the light of those requirements.

The Road to Progress

In conclusion I would summarize the fundamental requirements for sustained progress in the following terms:

There must be constantly increasing efficiency in production on the part of both labor and capital. Only by everlastingly improving technical processes and lowering the costs of production can we obtain progressively higher standards of living. To try to accomplish this result in any other way means simply tugging in vain at our collective bootstraps.

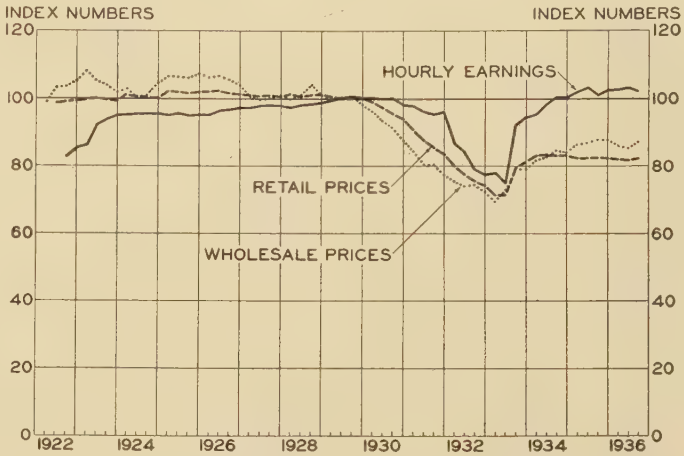


Fig. 11. Hourly earnings in manufacturing and prices of finished manufactured products

As efficiency is increased, the benefits must be broadly disseminated among the masses by means of high wages, low prices, or a combination thereof. This is essential for a double reason:

First, it is a fundamental requirement for social and political stability and the well rounded growth of a democracy. It is doubtful indeed if any economic or political system can permanently maintain itself unless it does maintain the goal of the greatest good for the greatest number.

Second, a broad dissemination of the benefits of technical progress is necessary to provide the market demands for an expanding industry. Under our capitalistic system we produce to sell goods in the market. If we increase capacity to produce without correspondingly increasing the capacity of the masses to purchase, we simply reach an impasse. Production schedules have to be restrained, with an accompanying retardation of the rate of economic progress.

Industrial growth, development, progress, require the expansion of consuming power step by step with the expansion of producing power. To put the matter in the simplest possible terms: Growth in the economic organism like growth in any other organism must proceed from the deepest and broadest possible rootage. It must rest on the expanding well-being of the entire population.

Some Engineering Contributions to Society

By R. C. MUIR
FELLOW AIEE

Getting more power from less fuel, and consequently providing the public with a dependable supply of electric power at low rates, is the goal toward which power engineers have aimed for many years. In striving toward this goal, they have made significant contributions to society, some of which are indicated in this article

RESEARCH and engineering have for their ultimate objectives the improvement of social and economic conditions and the conservation of natural resources. Some of the important advances achieved by power engineers in striving toward these objectives briefly are reviewed in this article. It is hoped that this discussion may give engineers a better appreciation of what they have done in this important field, but at the same time may serve as an antidote to complacency, as there yet remains much to be done.

Figure 1 shows data pertaining to the annual production of electric power from fuel for public use in the United States. In 1920, 27 billion kilowatt-hours were produced with 41 million tons of coal; in 1934, 57 billion kilowatt hours were produced and the coal consumption was just the same, 41 million tons. Thus, engineers have given the public more than twice the electric power without increasing the fuel consumption—a notable achievement in the conservation of fuel resources.

Figure 2 shows the improvement in fuel-power electric stations year by year, the performance of the best stations, and the still further improvement possible with the perfection of the mercury-steam station. As may be noted, it took 15 years for the *average* steam-station economy to equal the economy of the *best* station. Hence, 15 years from now the average steam-station economy might be expected to equal the best of today; in other words, for each unit of fuel used then the electric power produced will be $1^2/_3$ times as great as is produced by one unit of fuel today. Were it possible to have all fuel-burning stations equal to the best, only 26 million tons of fuel would be required to produce the 57 billion kilowatt-hours shown in figure 1 for 1934.

Fuel is only one item in the cost of power, and the engineer has not overlooked other items, the most important of which is reliability or availability factor. Coincident with the improvement in efficiency, the reliability has increased, so that the capacity factor has increased and the power generated per dollar of plant investment has materially increased.

It would be impracticable in this article to cover many of the engineering phases that have brought about this improvement, but the turbine generator is representative of the progress made and the problems confronting the engineer.

One of the most important factors in recent power-plant development is the ability to utilize high-temperature steam: that is, steam at 850 to 925 degrees Fahrenheit. This is permitting an increase in the use of high-pressure steam without resuperheating and its attendant complication, and gives a low-cost, simple, and highly efficient installation.

The ability to use high-temperature steam has been dependent upon the development of alloy steels having high creep strength at high temperatures. Ordinary steels are subject to a slow growth or plastic deformation called "creep" at these temperatures when under any appreciable stress.

This precluded the development, up until a few years ago, of turbines to utilize steam at temperatures higher than 750 degrees Fahrenheit. Now, materials are available that permit a stress at high temperatures of from 3 to 4 times what would have been permissible with older materials. This makes it possible to utilize parts of practicable proportions.

The General Electric Company has developed what might be called a second line of defense against high temperature by building some high-temperature turbines with a "double shell." In this construction, the turbine wheels are surrounded by an inner shell carrying its own bolting flange. This shell in turn is surrounded by a second shell which also is bolted at the horizontal joint. The space between is filled with steam at a pressure of about 40 to 50 per cent of the pressure of the steam in the inner shell and at a temperature 50 to 75 degrees lower. The stresses thus are divided between 2 shells so that each can be made thinner than it would otherwise have to be. Figure 3 shows this principle embodied in an actual design.

One of the most outstanding recent advances in the generation of electric power is the superposition on existing steam plants of high-pressure turbines operating at high back-pressure. These turbines take in high-pressure high-temperature steam, develop a certain amount of power, and discharge the steam from their exhausts into the present steam headers of the low-pressure stations. In this way it is possible to increase the capacity of present stations from 40 to 90 per cent, depending upon conditions.

Theoretically, the increased capacity should require an increased coal consumption of about $^1/_3$ pound per kilowatt-hour chargeable to the capacity so installed. Actually, the increased efficiency of the new boilers required by the superposition so reduces the fuel consump-

Essential substance of an address presented at a meeting of the AIEE New York Section, December 9, 1936.

R. C. Muir is vice-president in charge of engineering, General Electric Company, Schenectady, N. Y. He is a past-chairman of the AIEE Schenectady Section, and has served on the Institute's committees on protective devices and education.

tion chargeable to the old station as to make the 40 to 90 per cent additional capacity obtainable at no increase in fuel consumption whatever.

Since the additional capacity obtained by means of superposed turbines entails no additional fuel cost, it is in this respect on the same basis as a water-power plant; and since the installation cost is from $^1/_2$ to $^1/_3$ the cost of a water-power plant, it can be seen that generating capacity obtained in this way is achieved at a very great economy. That the industry is fully alive to this is attested by the fact that the turbines of this type ordered by public utilities during the past 2 years comprise about $^1/_3$ the capacity of all turbines ordered by them during that period. The remainder, of course, have been condensing turbines. A typical superposed installation is shown in figure 4.

One of the outstanding recent installations of condensing turbines is at the River Rouge Plant of the Ford Motor Company in Detroit, Mich. In the space originally occupied by 2 12,500-kw turbines, 2 new 110,000-kw units have been installed—9 times the capacity in the same space. The fuel consumption per kilowatt-hour is but 60 per cent as much as formerly.

The design and testing of a new type of steam-generating unit of good efficiency and relatively light weight, and requiring minimum space, recently was announced jointly by the General Electric, Babcock & Wilcox, and Bailey Meter companies. This new unit has been named the "steamotive." In it, steam is generated at high pressure and temperature; and fully automatic control in response to changes in demand has been incorporated. The units are intended for capacities of from 2,000 to 10,000 horsepower.

Two such units already have been built. The first, now in service in the Lynn, Mass., works of the General Electric Company, is used to test marine and other small turbines (see figure 5). It has an output of 21,000 pounds of steam per hour at a pressure of 1,500 pounds per square inch. The other, a completely co-ordinated power-generating plant incorporating the "steamotive" and turbine-generator, with a capacity of 10,000 pounds per hour and furnishing steam to a turbine at 1,200 pounds per square inch and 950 degrees Fahrenheit, is being installed in a small isolated plant of a large industrial concern to supply electric power and low-pressure steam for building heating. Both are oil-fired.

Two oil-fired "steamotive" units, each with a capacity of 40,000 pounds of steam per hour, are now being constructed for the Union Pacific Railroad for driving 2 2,500-horsepower electric locomotives. These units will furnish steam to the turbines at 1,500 pounds per square inch and 950 degrees Fahrenheit.

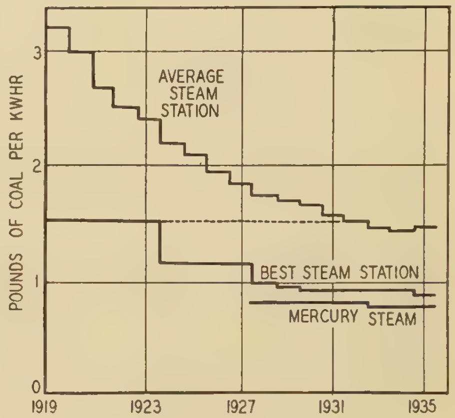


Fig. 2. Fuel consumed per unit of electric power produced in stations in the United States from 1919 to 1935, inclusive

Indicating the compactness of the "steamotive" unit, the one for Lynn was shipped complete from Schenectady on a railroad flatcar.

Objectives sought in the design of the new equipment are high steam pressure and temperature, minimum weight and size per unit of steam produced, wide range of capacity with ability of the unit to respond quickly to wide variations in load conditions, adaptability to wide range of fuels, completely co-ordinated auxiliaries, completely co-ordinated automatic control, and units of simple design and constructed in sizes small enough to be portable.

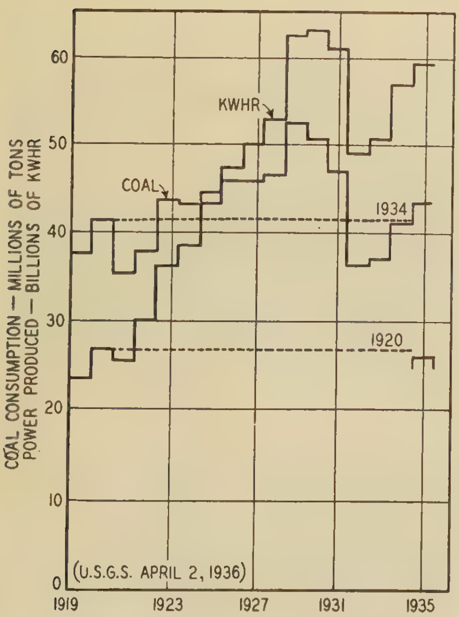


Fig. 1. Electric power produced for public use, and fuel consumed, in steam-electric stations in the United States from 1919 to 1935, inclusive

Hydrogen Cooling

A notable example of the value of engineering research in effecting a more economical use of construction materials, and greater economy of machine operation, is the development of hydrogen cooling as applied to rotating electrical machines. For years practically all classes of rotating electrical machinery were cooled with air, chiefly because it was more convenient to use than anything else. Then research showed that this practice was wasteful—that machines would operate more efficiently in gases other than air, and with a greater output per pound of material. Chief among these gases is hydrogen. This gas has a density only $^1/_{14}$ that of air, and as a result the windage and ventilation losses of a rotating machine operating in hydrogen would be reduced to $^1/_{14}$ of their value in air. The thermal properties of hydrogen also are distinctly superior to those

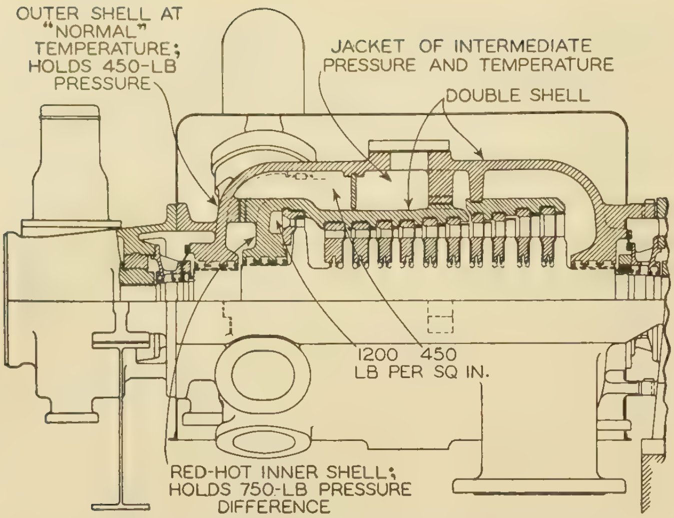


Fig. 3. Diagram showing construction of double-shell steam turbine for high pressure and temperature

of air. Hence, by operation in hydrogen, instead of air, up to 25 per cent greater output may be obtained from a machine of given physical dimensions for the same temperature rise of the parts.

The first applications of hydrogen cooling to rotating machines were to synchronous condensers and frequency changers. So successful have these applications been, that in the past 8 years 17 hydrogen-cooled machines of these types, having a combined capacity of nearly 500,000 kva, have been placed in service.

An even greater economic gain may be realized in the application of hydrogen cooling to high-speed turbine generators. With this class of machines, the windage and ventilation losses with air cooling comprise about half the full-load losses. Hence the use of hydrogen reduces the total losses by nearly half, corresponding to a gain of about 1 per cent in efficiency.

In one type of hydrogen-cooled turbine-generator, heat is extracted from the hydrogen in 4 surface coolers located within the generator housing and through which water is circulated. Because of the smaller losses and the improved performance of these coolers in hydrogen, their size is only about 40 per cent of that of the coolers of an air-cooled machine of equal rating. The volume of active material in such a machine is about 20 per cent less than would be required for an air-cooled machine of equal rating. To prevent the escape of hydrogen from the generator housing along the rotating shaft projections a sealing gland is provided in each bearing, which is supplied with vacuum-treated oil from a system operating in parallel with the bearing lubricating system.

In another type of hydrogen-cooled turbine-generator only the rotor is cooled with hydrogen, the stator being cooled by a number of hollow metal pads located between the core laminations and through which water is circulated. At the center of the core, pads with radial fins are provided, which serve both to remove the heat from the stator and to extract the losses from the hydrogen which has cooled the rotor. This type of installation requires the circulation of about 50 per cent less hydrogen than the other type, thus making possible the use of smaller fans and a shorter machine.

Commercial development of the hydrogen-cooled turbine-generator has just begun, but its importance to the industry is indicated by the fact that 17 machines of this type, with a combined output of nearly 850,000 kw, are now under construction. The yearly fuel saving for these 17 machines, as the result of using hydrogen cooling, is an item of some magnitude.

Improvements in Distribution

After the power is generated, it must be delivered to the consumer with as little loss as possible, in suitable form as to constancy of voltage, and under suitable conditions as to continuity of service or availability. This is not a matter of just using large electrical conductors, but rather a scientific arrangement of interconnections of conductors, placement of transformers, protective and regulating devices, and a reduction of losses in trans-

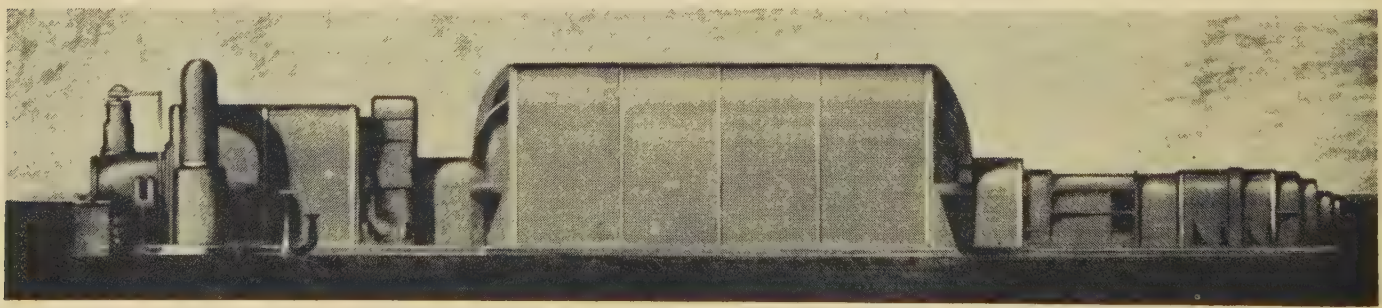


Fig. 4. Hydrogen-cooled 3,600-rpm 40,000-kw generator driven by high-pressure high-temperature turbine, now being built for superposed installation in the Logan, W. Va., station of the American Gas and Electric Company

Turbine: Pressure, 1,250 pounds per square inch; temperature 925 degrees Fahrenheit (red hot). Double-shell construction. Superposition of this unit will add 86 per cent to station capacity but with only a moderate increase in fuel consumption

Generator: Windage losses reduced (by use of hydrogen) to 10 per cent of what these losses would be if the machine were operated in air. Water-cooled stator. Aluminum field winding. Full load losses 1.4 per cent; full load efficiency 98.6 per cent

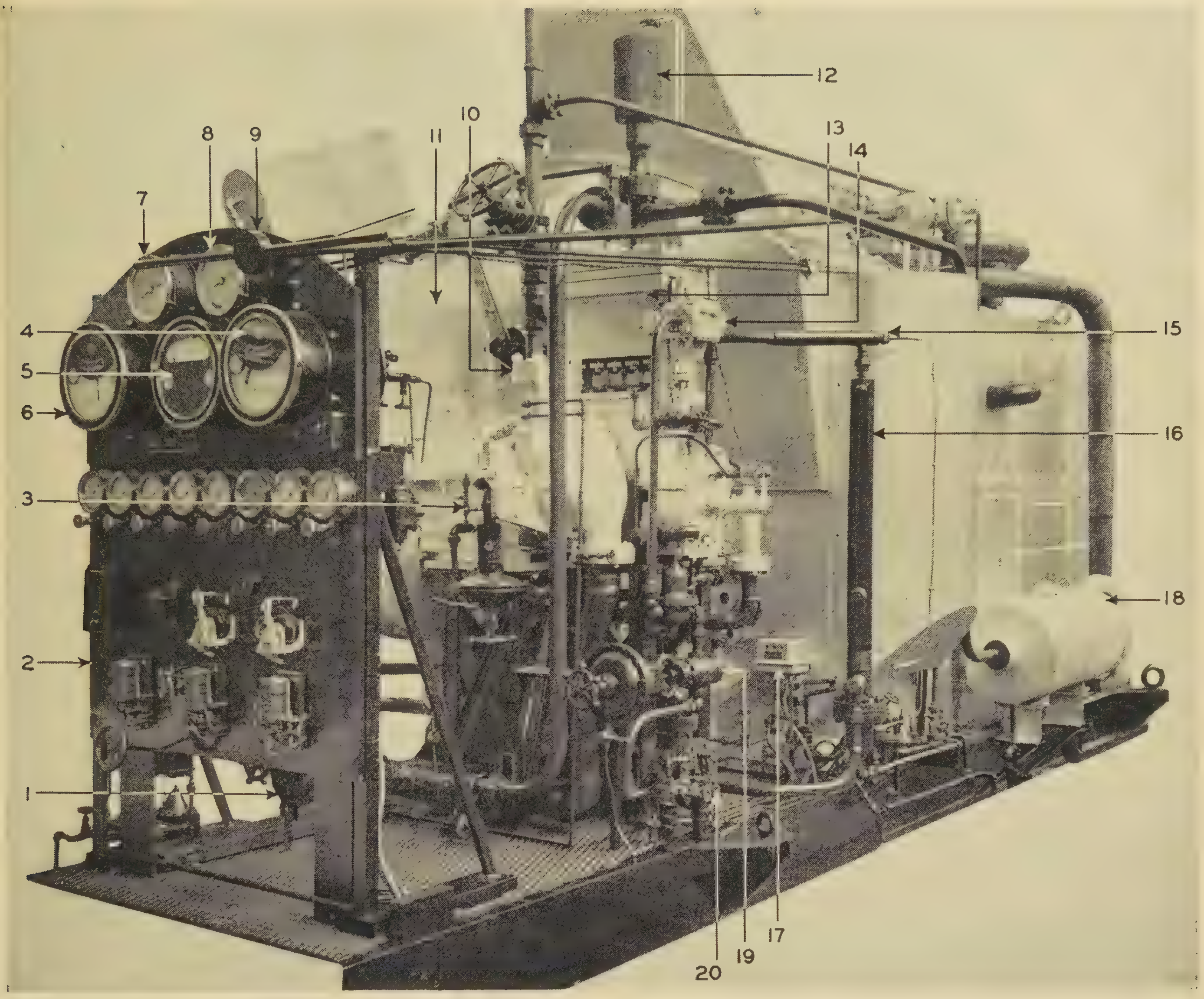


Fig. 5. Developmental "steamotive" unit

1. Governor control valve
2. Automatic lighting equipment
3. Drive-turbine steam valve operator
4. Oil flow-air flow controller
5. Steam-flow indicator
6. Drum-level controller
7. Steam-temperature indicator, high-temperature trip
8. Steam-pressure controller, high-pressure trip
9. Steam-output regulating valve
10. Auxiliary-set drive turbine
11. Blower
12. High-pressure surge chamber
13. Boiler feed pump
14. Fuel-oil pump
15. Fuel-oil temperature control
16. Fuel-oil heater
17. Fuel-oil shut-off valve for automatic lighting equipment
18. Feedwater heater
19. Fuel-oil control valve
20. Fuel-oil measuring orifice

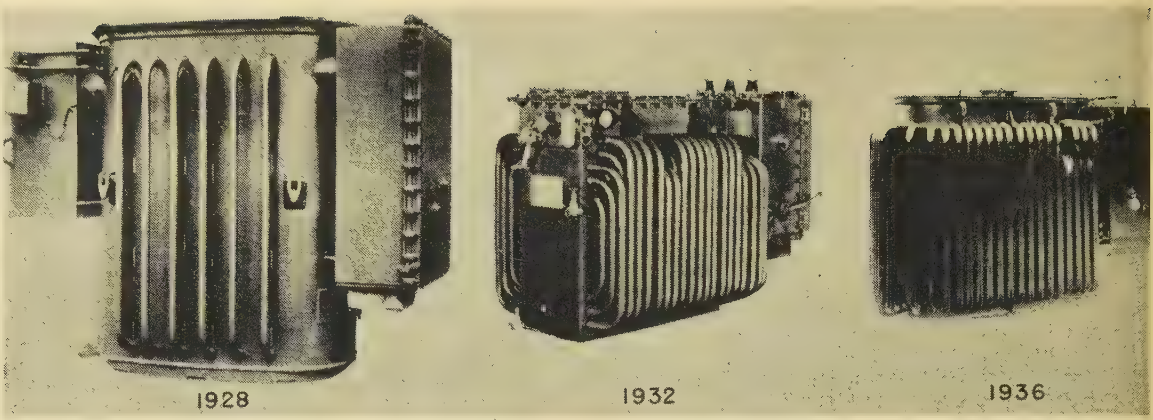
formers and regulating devices. The average distribution losses of the power systems of the United States in 1920 were $21^1/_2$ per cent; in 1936 this had been reduced to 15 per cent.

The marked and continuing improvement of transformer efficiency has played an important part in reducing the distribution losses. Since 1920 the losses of distribution transformers have been reduced an average of 20 per cent. The average full-load losses of power transformers have been reduced 45 per cent, while the core losses have been reduced $62^1/_2$ per cent over the same period. Figure 6 illustrates the rapid advance in the design of network transformers.

Improvements in Power Cable

Paralleling the improvement in transformers, it is interesting to note the progress made in paper-insulated cable since 1920. Previous to 1921 the highest voltage underground cable in use in the United States was 3-conductor 26-kv Y-grounded cable. In 1921, the first 3-conductor 33-kv cable in the United States was installed, but trouble developed and the operating voltage had to be reduced to 22 kv. In 1923 the first 66-kv single-conductor solid-type paper-insulated cable in the United States was installed, and in 1927 *the first* commercial installation in the world of 132-kv oil-filled cable

Fig. 6. Comparison of 1928, 1932, and 1936 network distribution transformers



	1928	1932	1936
Approximate vault space required (feet)	17 by 4.5 by 9 deep	14 by 4.5 by 8 deep	11 by 4 by 6 deep
	100%	56.5%	29.7%
Efficiency	98.5%	98.7%	98.7%
Weight (oil-filled)	100%	82.5%	82.5%

was put into service in the United States. Approximately 900 miles of oil-filled cable is now in service, and there has not been a single electrical failure in this cable in the United States. There is an installation of 230-kv oil-filled cable abroad but none operating at this voltage in this country, although manufacturers are prepared to supply it. Laboratory and field tests have been carried on for several years to determine if 230-kv oil-filled cable is feasible, and these tests are favorable.

Progress in the development and application of high-voltage paper-insulated cable has been made possible by improved materials and better manufacturing methods, and also by the development of the oil-filled cable. Thoroughly washed wood-pulp paper has taken the place of the oiled manila paper, and fluid oils have taken the place of the old petrolatum compounds. Low ionization has resulted from much better vacuum equipment and the complete filling of the cable with insulating oil; dielectric losses have been greatly decreased by the improvements in the paper and the oil. Dielectric losses at operating temperatures have been greatly reduced since 1925. This reduction in losses in the solid type of cable has been approximately 60 per cent, and in the oil-filled cable since 1927 approximately 40 per cent.

Another advance in distribution equipment is illustrated in figure 7.

Direct-current power transmission is very attractive from many points of view. It offers the possibility of operating cables with negligible dielectric losses at greatly increased voltages with consequent reduction in cable cost, and also a means of obtaining nonsynchronous ties between power stations. The General Electric Company has a developmental installation, but at present this is regarded as just another laboratory step which ultimately may come into commercial use and still further reduce transmission losses.

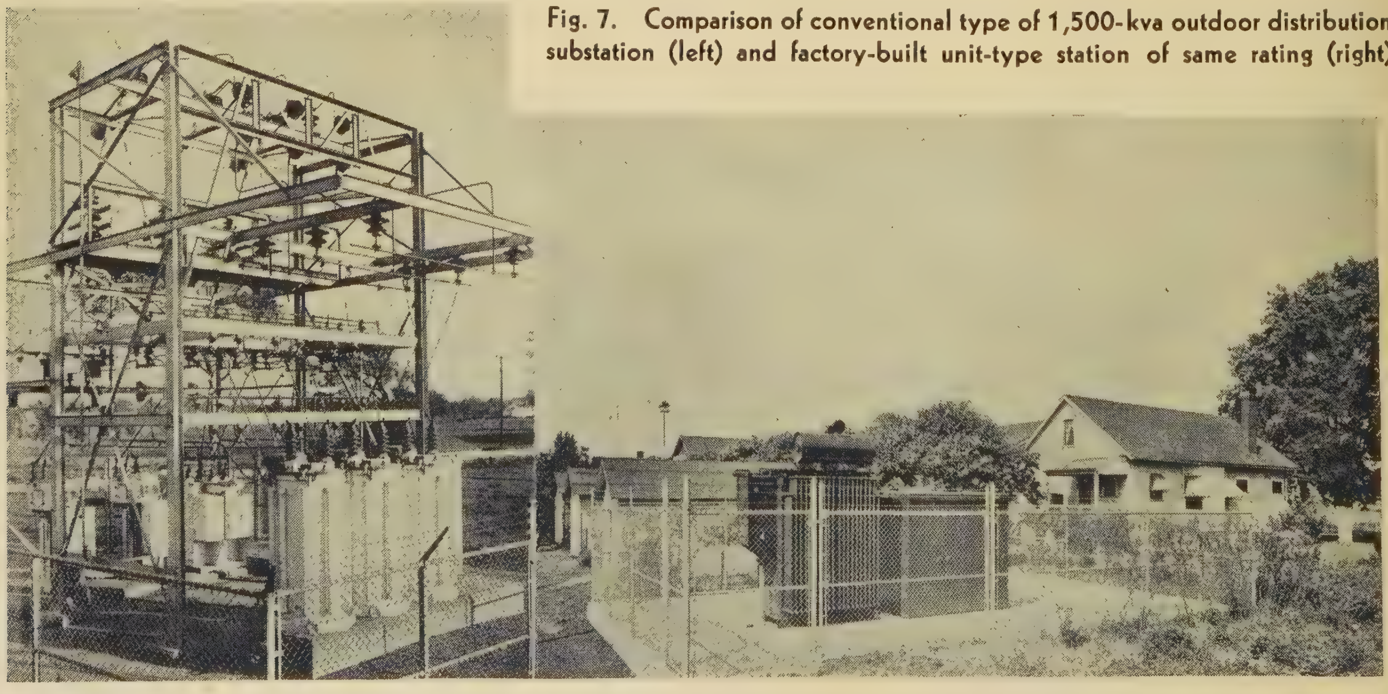


Fig. 7. Comparison of conventional type of 1,500-kva outdoor distribution substation (left) and factory-built unit-type station of same rating (right)

nprovements in Electric Appliances

After the power has reached the consumer, it should e used efficiently in his appliances. As examples, im-rovements in 2 appliances will be cited—the incandes-ent lamp and the household refrigerator.

More than 880,000,000 incandescent lamps were manu-ictured in 1936. For each kilowatt-hour the users f these lamps will receive $^1/_3$ more light than they did rom lamps of the same wattage in 1920, and each lamp rill cost $^2/_3$ less than in 1920.

At no time in the past has there been more activity 1 lighting research than at present. Illumination studies re under way on a more extensive scale than ever be-ore, and illuminating engineers have many new types f lamps to experiment with—the sodium lamp, the igh-intensity mercury-vapor lamp, and fluorescent lamps, ll subject to further development.

There are in service now approximately 7,000,000 ousehold electric refrigerators. Today, 3 electric re-rigerators operate with the same electric-power con-umption as one required in 1926, and the user may urchase a much superior unit for less than half the mount he paid in 1926. Great advances have been nade in styling or in improving the appearance of re-rigerators and all household devices. This is illustrated 1 figure 8.

This improvement has been a matter of putting into hese devices the same research, high technical ability, nd ingenuity as has been applied to larger apparatus.

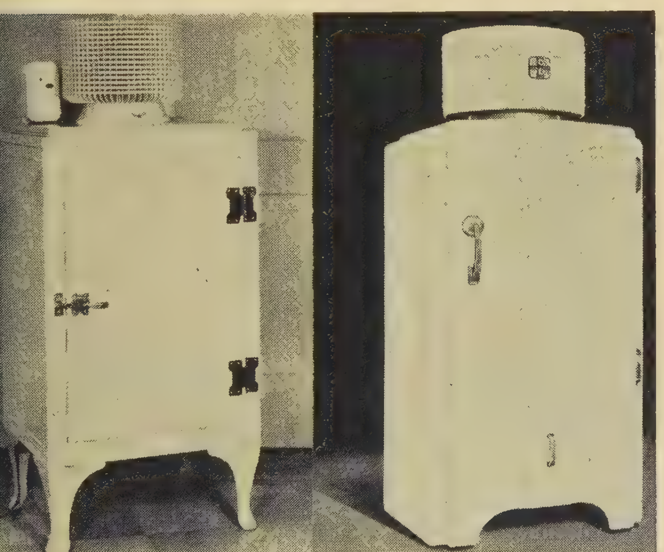
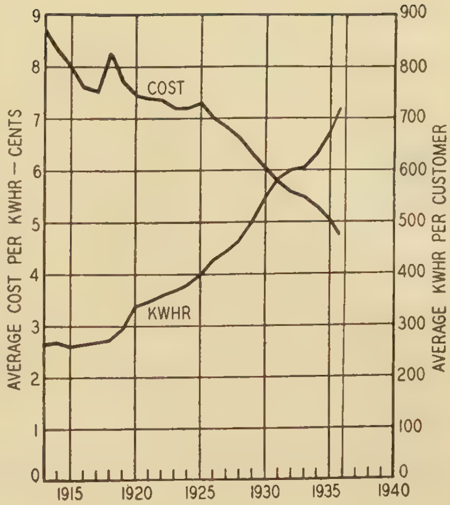


Fig. 8. Comparison of 1927 and 1937 domestic electric refrigerators

	1927	1937
Net volume (cubic feet)	6	6
Installed price (approximate)	$310	$200
Capacity, Btu per hour	340	530
Economy, watt-hours per Btu	450	340
Ice-freezing rate, pounds per hour	0.66	2.04
Average kilowatt-hours per month	55	28
Pounds weight per Btu (unit only)	0.662	0.258

Fig. 9. Consumption of electricity in domestic service and average cost per kilowatt-hour, since 1913



Similar advances have been made in electric ranges and water heaters, washing machines and ironers, radios, food mixers, toasters, and heating appliances.

Air conditioning is getting under way and will be greatly extended. One of the big problems in air conditioning is the quiet and efficient movement of air; this has stimulated fan research, the results of which already have effected remarkable improvements.

A new household servant has appeared in the disposal unit which macerates waste food from the kitchen, and discharges it into the sewage system. Some day, perhaps, this will be as compulsory as the sewage system itself is today.

The result of all this is shown in figure 9, which depicts how the power companies have taken advantage of these engineering achievements in power generation and transmission and distribution, and have passed them along to the user in the way of lower and lower rates so that the average rate to the domestic consumer today is but little more than half what it was in 1916. The consumer has taken advantage of the lower rates, and of the new and improved lamps and devices, and has increased the average domestic use from 260 kilowatt-hours per year to 709, or more than double. Furthermore the service has improved as to reliability, continuity, and constancy of voltage. What does the consumer pay for this service? If he uses the average 700 kilowatt-hours per year and pays the average rate, he pays just one week's wages for the average American workingman. What else can he purchase that does so much for him—a whole year's electric service for one week's pay? He can buy an electric refrigerator for one month's pay, a better refrigerator than the working man in Europe can buy for 3 months' pay.

In conclusion, then, it may be said that the research and engineering objective of power engineers is to obtain more and more electric power from each unit of fuel, to lose less and less of that power in distributing it to the user, and to have each unit of power do more and more for the user, all to the end that the maximum benefits may be obtained from our natural resources to the best social and economic interest of the nation.

Employment in the Engineering Profession

Between 1930 and 1934 there was a substantial net loss of employment among those engineers in the United States who entered the profession before 1930, and a considerable absorption in employment of newcomers to the profession. This is one important conclusion reached by the Bureau of Labor Statistics of the United States Department of Labor after analyzing reports from 52,589 professional engineers obtained in the 1935 survey of the engineering profession conducted by the Bureau at the request and with the co-operation of American Engineering Council. This article,* third in the series reporting the results of this survey, presents data pertaining to the employment of engineers during 1929–34.

ANALYSIS has been made by the Bureau of Labor Statistics, United States Department of Labor, of reports from 52,589 professional engineers, showing the kinds of employment engaged in at specified periods. The study was undertaken in May 1935, at the request of the American Engineering Council. The following general findings were established by this analysis:

Over the 5-year period ending December 1934, the number of persons in the engineering profession increased by 25.3 per cent. This rate of increase was much in excess of available engineering employment opportunities. The growth among the several professional classes over the period 1930–34 ranged from 17.6 per cent for mining and metallurgical to 62.5 per cent for chemical and ceramic engineers.

The lack of opportunities for engineering employment differed markedly among the professional classes. Thus, over the 5-year period, and for the profession as a whole, private engineering employment declined by 8.2 per cent, but it increased by more than a third for chemical and ceramic engineers. There was little increase or decrease for electrical, mining and metallurgical, and mechanical and industrial engineers. In the case of the civil engineers, however, there was a decrease of about $^1/_3$ in private engineering employment.

All professional classes participated in the increases in employment of engineers by public authorities. The civil engineers were most affected. The proportion of this group employed by public authorities increased from 40.0 per cent in 1929 to 48.5 in 1934.

The fact that available engineering opportunities did not keep pace with the increase in the number of men trained to enter the profession brought about changes in the proportions of those who were unemployed or engaged in nonengineering work.

In 1929 private engineering furnished by far the greatest employment for engineers. For civil engineers this covered 54.3 per cent. There was a range of from 80.6 to 87.3 per cent among the 4 remaining professional classes. By December 1932 private engineering among civil engineers had dropped to 37.6 per cent, and by December 1934 to 31.8 per cent. There was also a continuous decline in this type of employment among electrical engineers; only 63.1 per cent reporting such employment in December 1934. There was only a slight improvement over 1932 for the remaining professional classes. In 1934 these 3 averaged 69.1 per cent.

Nonengineering employment increased sharply from 1929 to 1932 and in equa[l] measure for all professiona[l] classes, absorbing many mor[e] engineers than did public engi[-] neering, in which employmen[t] also increased. But despit[e] the fact that the proportion[s] of all engineers in nonengi[-] neering employment rose from 6.3 per cent in 1929 to 12.[?] per cent in 1932, there was a[n] even larger increase in un[-] employment. This situatio[n] was common to all professiona[l] classes.

Between December 193[2] and December 1934 there were further increases in nonengineering employment for al[l] professional classes. The increases were not so grea[t] as between 1929 and 1932. Unemployment declined fo[r] all professional classes, except for civil engineers.

The sharpest increases in public-engineering employment occurred in the period 1932–34.

Of all engineers who reported being professionally active prior to 1930, only 46.2 per cent were in the employ o[f] private firms in 1934; in 1929, 62.2 per cent were s[o] engaged. Federal government employment provided fo[r] 10.1 per cent in December 1934; in 1929, this field gave employment to only 5.3 per cent.

Over the period 1930–34 there was a remarkable stability in the number of engineers classified as independent consultants, and those engineers engaged in the teaching of engineering subjects. This was also true of those i[n] the employ of state and county, and municipal and othe[r] public authorities, especially if considered together.

The net new private-firm employment that developed between 1930 and 1934 was secured by newcomers wh[o] entered the profession in this period. In absolute number, 5,003, or 16 per cent, of the engineers active in the profession before 1930 suffered loss of engineering employment. Some 3,112, or 18 per cent, of the new entrants found engineering work with private firms. The increase in public engineering employment was shared by both older and younger engineers.

Scope and Method of Study

The primary objectives of this analysis were to determine what kinds of engineering employment were most stable, and what types of substitute employment pro-

* An article prepared by Andrew Fraser, Jr. of the Division of Hours, Wages, and Working Conditions, Bureau of Labor Statistics, United States Department of Labor, which article was published in the April 1937 issue of *Monthly Labor Review*. Articles reporting other phases of this survey were published in ELECTRICAL ENGINEERING as follows: "Professional Aspects of Engineering Education," August 1936, pages 863–7; "Unemployment in the Engineering Profession," February 1937, pages 216–23. A detailed report of the survey will be published later in bulletin form by the Bureau of Labor Statistics.

Table I—Distribution of All Professional Engineers by Employment Status Reported at End of 1929, 1932, and 1934

(Figures adjusted as explained on page 525)

Employment Status	Number 1929	Number 1932	Number 1934	Per Cent 1929	Per Cent 1932	Per Cent 1934	Increase or Decrease in Number 1929 to 1932	1932 to 1934	1929 to 1934
Grand total, United States	31,252	35,691	39,161	100.0	100.0	100.0	+4,439	+3,470	+7,909
Engineering employment	29,051	27,787	30,299	93.0	77.9	77.4	−1,264	+2,512	+1,248
Private[a]	22,456	19,797	20,619	71.9	55.5	52.7	−2,659	+ 822	−1,837
Public[b]	6,595	7,990	9,680	21.1	22.4	24.7	+1,395	+1,690	+3,085
Nonengineering employment	1,969	4,290	5,523	6.3	12.0	14.1	+2,321	+1,233	+3,554
Unemployment	232	3,614	3,339	0.7	10.1	8.5	+3,382	− 275	+3,107

a. Includes those engineers in the employ of private firms, independent consultants, reporting "any other employment," and teaching.
b. Includes those engineers in the employ of federal, state, county, municipal governments, and other public authority.

fessional engineers found during the depression years, 1930–34, inclusive.

The engineer was requested to check his employment status against only 1 of 14 items for each of the 3 years ending December 31, 1929, 1932, and 1934. In view of the small number reporting in some categories, similarity in the detailed distributions, and the desirability of discussing unemployment and related data as a whole, these 14 categories were reduced to 8 and are designated in this article thus: (1) private firm,[1] (2) independent consultant, (3) teaching, (4) Federal, (5) state and county, (6) municipal and other public authority, (7) nonengineering employment, (8) total unemployment.[2] In the ensuing discussion items 1 to 3 inclusive, and 4 to 6 inclusive are hereafter referred to, respectively, as private engineering employment and public engineering employment, and these 2 in combination as total engineering employment.

Employment Status of Engineers, 1929–34

During the period 1930 to 1934, inclusive, the total number of engineers seeking employment was increased by almost 10,000 per year, largely through the addition of new college graduates. Thirty-two per cent of these recent college graduates reported to the bureau, in contrast to 15 per cent of those who were actively engaged in the profession prior to 1930. This disparity necessitated adjusting the sample to obtain the over-all distributions of employment status for 1932 and 1934, thus: The number of engineers graduating in 1930–34 and reporting employment status for 1932 and 1934 were reduced in the ratio of 15 to 32. These derived totals were then added to the remaining reports for 1932 and 1934. This was possible because for separate age groups among both the younger and older engineers the percentage of replies shows homogeneous sampling within these 2 groups. In determining the adequacy of these samples no allowances were made for deaths or severances from the profession occurring between December 1929 and December 1934.

These distributions for the years 1929, 1932, and 1934 are presented in table I for the profession as a whole.

Between December 1929 and December 1932 the total number of professional engineers in the sample increased by 4,439, from 31,252 to 35,691. There was a further increase of 3,470 to 39,161 by December 1934. The total increase from 1929 to 1934 amounted to 25.3 per cent.

This increase took place during 5 years of depression in which available engineering opportunities were insufficient to absorb the supply of engineers. For December 1932, 3,614 reported unemployment. The percentage of those reporting unemployment declined from 10.1 at the end of 1932 to 8.5 at the end of 1934. But in the face of the continuing influx of engineers, the absolute number of those unemployed declined only slightly to 3,339 at the end of 1934. Furthermore, while the presence of 6.3 per cent of the professional engineers in nonengineering employment in 1929 indicates this was even then an established and normal outlet for them, there was an enormous increase in such work between 1929 and 1932. There was a further, but smaller, increase in nonengineering work between 1932 and 1934. The number reporting themselves as engaged in such work increased from 1,969 in 1929 to 5,523 by December 1934. Among the engineers reporting, 12.0 and 14.1 per cent were engaged in nonengineering work in December 1932 and 1934, respectively. There is reason to believe, from a preliminary examination of income data, that the specific nonengineering work of many of those reporting in 1934 was much more frequently of a makeshift character than in 1929.

Engineering employment as a whole declined 4.4 per cent between 1929 and 1932. There was a rise by December 1934. The number in the adjusted sample engaged in engineering work increased from 29,051 in December 1929 to 30,299 in December 1934, but this was due primarily to the increases in the public employment of engineers. Private employment decreased by 11.8 per cent from 1929 to 1932. Despite some increase from 1932 to 1934, it was still 8.2 per cent below the 1929 level at the end of the 5-year period 1930–34.

The dependence upon public employment is further evidenced by the fact that although both classes of engineering employment increased between December 1932 and December 1934, the absolute increase reported in private employment was only half of that obtaining in employment with public authorities. Relative to the numbers so employed in 1932, the rate of increase in public employment was almost 5 times as great as that in private employment.

1. Includes also those reporting as employees of private consulting firms and under "any other employment" in question 6.
2. Includes also those reporting work relief and direct relief.

Table II—Employment Status at End of 1929, 1932, and 1934 of All Engineers Reporting, by Professional Class

(Figures adjusted as explained on page 525)

	Number of Engineers														
				In Engineering Employment						In Nonengineering Employment			Unemployed[c]		
	Total			Total Private[a]			Total Public[b]								
Professional Class	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934
Total, United States	31,252	35,691	39,161	22,456	19,797	20,619	6,595	7,990	9,680	1,969	4,290	5,523	232	3,614	3,339
Chemical and ceramic	1,470	1,931	2,389	1,217	1,322	1,640	103	122	143	143	320	459	7	167	147
Civil, agricultural, and architectural	13,786	15,330	16,365	7,477	5,760	5,191	5,510	6,620	7,941	694	1,413	1,556	105	1,537	1,677
Electrical	6,112	7,276	8,117	5,238	4,940	5,137	350	456	623	493	1,155	1,759	31	725	598
Mechanical and industrial	8,455	9,587	10,609	7,374	6,729	7,512	504	643	802	517	1,190	1,518	60	1,025	777
Mining and metallurgical	1,429	1,567	1,681	1,150	1,046	1,139	128	149	171	122	212	231	29	160	140

a. Includes employees of private firms, independent consultants, "any other employment," and teaching.
b. Includes federal state county, and municipal governments, and other public authority.
c. Includes direct relief and work relief.

The preceding analysis is concerned only with the engineering profession as a whole. Corresponding data for each professional class are presented on an adjusted basis in table II.

Over the 5-year period ending December 1934, the number of persons in the engineering profession increased by 25.3 per cent. The corresponding increases for the separate professional classes ranged from 17.6 per cent for mining and metallurgical engineers to 62.5 per cent for chemical and ceramic engineers (table III).

In no professional class did total engineering employment keep pace with the growing number of engineers. The closest balance between the increase in number of engineers and the increase in total engineering employment was 62.5 per cent to 35.1 per cent for chemical and ceramic engineers. That is, without displacement of such engineers in the profession in 1929 about half of their increase in number could have been absorbed in engineering work. The next highest increase in number, namely, 32.8 per cent, occurred among electrical engineers. This was met by an increase of only 3.1 per cent in their total engineering employment. Mechanical and industrial engineers fared somewhat better. Their numbers increased by 25.5 per cent, while opportunities for engineering employment increased by 5.5 per cent. Roughly, $^1/_5$ of the total increase in number of all engineers between 1930 and 1934 was provided for by the growth of new jobs. Clearly, the wide variations in the rates of increase in these professional classes had an important bearing upon the nature of their employment distributions in the period 1929–34.

Table III—Per Cent of Change in Engineering Employment, by Professional Class, 1929 to 1934

(Figures adjusted as explained on page 525)

Professional Class	Per Cent of Increase in Each Professional Class, 1929–34	Per Cent of Increase or Decrease, 1929–34 in— Total Engineering Employment	Private[a] Engineering Employment	Public[b] Engineering Employment
Total, United States	+25.3	+4.4	−8.2	+46.8
Mining and metallurgical	+17.6	+2.5	−1.0	+33.6
Civil, agricultural, and architectural	+18.7	+1.1	−30.6	+44.1
Mechanical and industrial	+25.5	+5.5	+1.9	+59.1
Electrical	+32.8	+3.1	−1.9	+78.0
Chemical and ceramic	+62.5	+35.1	+34.8	+38.8

a. Includes employees of private firms, independent consultants, "any other employment," and teaching.
b. Includes employees of federal, state, county, and municipal governments and other public authority.

The data for private and public engineering in table III accentuate the differences in available engineering opportunities for each professional class. Thus, over the 5-year period, and for the profession as a whole, although private engineering employment declined by 8.2 per cent it increased by more than $^1/_3$ for chemical and ceramic engineers. There was little increase or decrease for electrical, mining and metallurgical, and mechanical and industrial engineers; but for the civil engineers, there was a decrease of about $^1/_3$ in private engineering employment.

By contrast, no professional class was excepted from the increases which took place in public engineering employment. It was the civil engineers, however, who were most affected. For them public employment was an important field in 1929 when 40 per cent of all civil engineers were so engaged. The 44.1 per cent increase by 1934 in the amount of such employment reported meant an absolute increase of 2,431 jobs over the 5-year period. In contrast, less then 6.0 per cent of electrical and mechanical engineers had been employed by public authorities in 1929. By December 1934, although the numbers of them so engaged had increased by 78 and 59.1 per cent, respectively, the absolute increases in jobs reported were only 273 for electrical and 298 for mechanical and industrial engineers. For chemical and ceramic, and mining and metallurgical engineers, the absolute increases were, respectively, 40 and 43.

Since the available engineering opportunities did not keep pace with the increases in men trained to enter the profession, there must obviously have been changes in the proportions, first, of those engaged in engineering and second, of those unemployed,[3] or engaged in nonengineering work. This is evidenced by considering the adjusted data presented in table IV.

3. For detailed discussion, see "Unemployment in the Engineering Profession," Electrical Engineering, February 1937, pages 216–23.

Private engineering employment furnished by far the greatest amount of employment to engineers. In 1929, even among civil engineers, 54.3 per cent were so employed. For the remaining 4 professional classes, the percentages ranged from 80.6 for mining and metallurgical to 87.3 for mechanical and industrial engineers. These proportions dropped sharply from 1929 to 1932 because of a decrease in the number of private jobs and an increase in the number of engineers. By December 1932, only 37.6 per cent of the civil engineers reported being in private engineering. The range for the remaining 4 professional classes was from 66.8 to 70.2 per cent. By the end of 1934, there was a further decrease in the proportions privately employed among both civil and electrical engineers. The former decreased to 31.8 per cent. Among electrical engineers, private engineering work had employed 67.8 per cent in 1932 as compared with 63.1 per cent in 1934. There was only a slight improvement over 1932 for the remaining professional classes.

In all classes, excepting chemical and ceramic engineers, the proportions engaged in public engineering increased from 1929 to 1934. The most pronounced shift occurred among the civil engineers, namely, from 40.0 per cent in 1929 to 48.5 per cent in 1934. This is some measure compensated for the large decline in the private engineering employment of this professional class. Indeed, as a result of public employment, the proportion of civil engineers in total engineering employment in both 1932 and 1934 was slightly higher than in any other professional class.

Lack of engineering employment opportunities in the period 1929–32 led to increases in both nonengineering employment and unemployment for all professional classes. In general, the loss of private employment occurred from 1929 to 1932. Nonengineering employment increased sharply, absorbing many more engineers than public engineering work, in which employment also increased. But despite the fact that the proportion of all engineers in nonengineering rose from 6.3 per cent in 1929 to 12.0 per cent in 1932, there was an even larger increase in unemployment. This situation was common to all professional classes.

There were further increases in the proportions engaged in nonengineering work among all professional classes in the period 1932–34. Among electrical engineers, the rate of increase in the proportion who were in nonengineering employment was $^3/_4$ of that which occurred in 1929–32. But for the remaining professional classes the corresponding rates of increase were only $^1/_3$ or less. In the case of civil engineers and mining and metallurgical engineers, there were almost no increases in the proportions engaged in nonengineering employment. For each of these groups there was a greater increase from 1932 to 1934 in public than in nonengineering employment. For civil engineers it was much larger. For mechanical engineers the proportions in public engineering rose from 6.7 per cent in 1932 to 7.6 per cent in 1934, whereas nonengineering embraced 12.4 per cent of all mechanical engineers in 1932 and 14.3 per cent in 1934. For mechanical engineers, therefore, the rate of expansion in public engineering employment was less than that which occurred in nonengineering employment.

Employment Status in Comparable Age Groups

Comparison of the distribution of employment status in 1929 of all engineers who entered the profession in the period 1925–29, with that in 1934 of a comparable group who entered the profession between 1930 and 1934, reflects the pressures to which new entrants were subjected during the depression years. It also emphasizes the abnormality of the employment status of the latter in 1934.

In 1929 only 5.3 per cent of the most recent graduates with professional training were in nonengineering work and 0.4 per cent were unemployed. In other words, all but $^1/_{20}$ of those who entered the profession in these 5 years were employed in engineering work in 1929 (table V). But in 1934, $^2/_5$ of the comparable group of recent engineering graduates[4] were not in regular professional engineering work. No less than 10.6 per cent of them were unemployed in December 1934, while 29.4 per cent reported being engaged in nonengineering work.

Of all recent engineers, both in 1929 and in 1934,

4. The term "engineering graduate" is used interchangeably with "entered the profession." The tabulations cover predominantly those who received first degrees in engineering in the years specified, but also include all "other" engineers (such as those whose college work was incomplete) who were 23 to 27 years old at the date of reported employment.

Table IV—Percentage Distribution of Engineers Reporting, by Employment Status and Professional Class, at End of 1929, 1932, and 1934

(Figures adjusted as explained on page 525)

	Per Cent of Total in Each Professional Class Reporting—											
	Engineering Employment						Nonengineering Employment			Unemployment[c]		
	Private[a]			Public[b]								
Professional Class	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934
Total, United States	71.9	55.5	52.7	21.1	22.4	24.7	6.3	12.0	14.1	0.7	10.1	8.5
Chemical and ceramic	82.8	68.5	68.7	7.0	6.3	5.9	9.7	16.6	19.2	0.5	8.6	6.2
Civil, agricultural, and architectural	54.3	37.6	31.8	40.0	43.2	48.5	5.0	9.2	9.5	0.7	10.0	10.2
Electrical	85.6	67.8	63.1	5.8	6.3	7.8	8.1	15.9	21.7	0.5	10.0	7.4
Mechanical and industrial	87.3	70.2	70.8	5.9	6.7	7.6	6.1	12.4	14.3	0.7	10.7	7.3
Mining and metallurgical	80.6	66.8	67.9	8.9	9.5	10.1	8.5	13.5	13.7	2.0	10.2	8.3

a. Includes employees of private firms, independent consultants, "any other employment," and teaching.
b. Includes employees of federal, state, county and municipal governments, and other public authority.
c. Includes direct relief and work relief.

approximately $^1/_5$ were engaged in the 3 categories of public engineering. In so far as any differences existed, there appears to have been a slight decline in the proportions of the 1930–34 group that secured public employment. The decrease in the percentage in state and county employment was only from 8.8 to 7.5. But municipal and other public authorities in 1929 had employed 5.4 per cent of the 1925–29 engineers, whereas in 1934 they employed only 2.4 per cent of those who entered the profession in the period 1930–34. On the other hand, the federal government employed a larger percentage of the recent graduates in 1934 than it had in 1929. For 1929, 6.5 per cent of the 1925–29 engineers reported themselves as having been employed by the federal government, whereas 9.2 per cent of the recent entrants to the profession were so employed in 1934.

In 1929 nearly $^3/_4$ of the recent engineers were in private engineering employment. Only 40.9 per cent of the 1930–34 engineers so reported for December 1934. Clearly, the abnormally large proportion of the new entrants to the profession who were unemployed or were compelled to find work of a nonengineering nature in 1934 was due primarily to the lack of opportunities in the principal field of engineering activity. A contributory factor of substantial importance, however, was that the number of those graduated from engineering courses in colleges was about 20 per cent higher from 1930 to 1934 than from 1925 to 1929. In number, this increase was about 10,000 individuals.

This dependence upon private engineering employment is common to the greater part of the engineering profession. A substantial number, however, is normally in the employ of public authorities. This is borne out by considering the distributions of employment status of all engineers reporting. These data are shown in table VI, divided into 3 broad classes, by age.[5]

Of all older engineers reporting for December 1929, it may be noted that 71.9 per cent were engaged in private engineering, 21.1 per cent in public engineering, 6.3 per cent in nonengineering work and only 0.7 per cent were unemployed. Of the 71.9 per cent in private engineering, 62.2 per cent were in the employ of private firms, 4.2 per cent in independent consulting work, and 5.5 per cent in teaching. In public engineering, the percentages for federal, state, and county, and municipal and other public authorities ranged from 5.3 to 7.4. This situation had an important bearing on the changes which occurred in the subsequent period, especially with regard to substitute employment.

Over the 5-year period there was a net change in the distributions of employment affecting 16.8 per cent of the "older" engineers; that is, of engineers who had entered the profession prior to 1930. In other words, out of every 1,000 engineers reporting, there were net changes in the employment status of 168 between 1929 and 1934. In absolute numbers, there were shrinkages of 5,255 jobs for engineers graduating prior to 1929. No less than 5,002 were separated from private firms. The remaining net losses of employment were distributed among those engaged in independent consulting (60), in teaching (16), and in municipal and other public employment (177). These decreases in employment opportunities for older engineers were not counterbalanced by increases in the other classes of engineering employment. In fact, 2,270 engineers reporting graduation prior to 1930 were still unemployed in December 1934, while 1,233 found employment in nonengineering work. Only 1,752 had been absorbed by increases in public engineering employment, $^1/_6$ with state and county authorities, and $^5/_6$, or 1,502, with the federal government.

The major part of the loss of employment for older engineers occurred from 1929 to 1932. In this period net shifts in employment had affected the status of 14.7 per cent of these men. The net change in the period 1932–34 involved only 4.0 per cent of them. Obviously, by December 1932 the engineering profession had suffered the major impact of the depression. Between December 1929 and December 1932 there were net losses of employment involving 4,608 engineers. Only 2 of the categories of employment were involved, namely, that with private firms, and that with municipal and other public authorities. But of the 4,608 positions concerned, the shrinkage of employment with private firms affected 4,530; the latter, only 78. Of these engineers, only 884 were able to find other types of engineering employment by December 1932; nearly 50.0 per cent of them entered federal-government employment, while $^1/_3$ entered state and

Table V—Comparative Employment Status of 2 Groups of Younger Engineers

Age Group	Number of Engineers						
			In Public Engineering Employment				
	Total	In Private[a] Engineering Employment	Federal	State and County	Municipal and Other Public Authority	In Nonengineering Employment	Unemployed[b]
1925–29 engineers, who were 23 to 27 years of age in 1929	6,997	5,151	452	618	375	371	30
1930–34 engineers, who were 23 to 27 years of age in 1934	16,872	6,910	1,544	1,272	401	4,959	1,786
	Per Cent						
1925–29 engineers, who were 23 to 27 years of age in 1929	100.0	73.6	6.5	8.8	5.4	5.3	0.4
1930–34 engineers, who were 23 to 27 years of age in 1934	100.0	40.9	9.2	7.5	2.4	29.4	10.6

a. Includes employees of private firms, independent consultants, "any other employment," and teaching.
b. Includes work relief and direct relief.

5. Table VI presents the absolute figures for all reports received without adjustment. It deals with the older and younger engineers separately and, therefore, no adjustment was required in these broad age classifications, though allowance did have to be made for the relatively large number of reports received from young engineers when the groups were treated in combination.

Older engineers comprise all those who were active in professional engineering prior to 1930. The younger engineers are those who entered the profession in the years 1930–34, inclusive, and are divided into 2 broad age groups, each designated by the graduating classes which they embrace, namely, 1930–32 engineers and 1933–34 engineers. Furthermore, in tabulating the data on employment status, homogeneity of the older and 1930–32 engineers was maintained. That is, in the case of the former, only those reporting for the 3 years 1929, 1932, and 1934 were used; in the case of the latter, only those reporting for the 2 years 1932 and 1934 were included. Analysis shows that the percentage eliminated was small.

able VI—Distribution of Older and Younger Engineers Reporting, by Employment Status, at End of 1929, 1932, and 1934

Employment Status	Number						Per Cent					
				Younger Engineers						Younger Engineers		
	Older Engineers[a]			1930–1932[b]		1933–1934[c]	Older Engineers[a]			1930–1932[b]		1933–1934[c]
	1929	1932	1934	1932	1934	1934	1929	1932	1934	1932	1934	1934
rand total, United States	31,252	31,252	31,252	9,469	9,469	7,403	100.0	100.0	100.0	100.0	100.0	100.0
ngineering employment	29,051	25,327	25,548	5,248	6,057	4,070	93.0	81.1	81.8	55.4	64.0	55.0
Private employment	22,456	18,142	17,378	3,532	3,926	2,984	71.9	58.1	55.7	37.3	41.5	40.4
Private firm	19,424	14,894	14,422	3,247	3,748	2,892	62.2	47.7	46.2	34.3	39.6	39.2
Independent consultant	1,303	1,459	1,243	50	25	17	4.2	4.7	4.0	0.5	0.3	0.2
Teaching	1,729	1,789	1,713	235	153	75	5.7	5.5	5.5	2.5	1.6	1.0
Public employment	6,595	7,185	8,170	1,716	2,131	1,086	21.1	23.0	26.1	18.1	22.5	14.6
Federal	1,647	2,063	3,149	531	1,008	536	5.3	6.6	10.1	5.6	10.6	7.2
State and county	2,632	2,884	2,882	927	872	400	8.4	9.2	9.2	9.8	9.2	5.4
Municipal and other public authority	2,316	2,238	2,139	258	251	150	7.4	7.2	6.8	2.7	2.7	2.0
onengineering employment	1,969	3,047	3,202	2,651	2,655	2,304	6.3	9.7	10.2	28.0	28.0	31.1
nemployment	232	2,878	2,502	1,570	757	1,029	0.7	9.2	8.0	16.6	8.0	13.9

Includes both graduates and "other" engineers who were professionally active prior to 1930.
Includes both graduates and "other" engineers who entered the profession in the years 1930–32.
Includes both graduates and "other" engineers who entered the profession in the years 1933 and 1934.

ounty employment. There were 156 additional engi- ieers reporting themselves as being independent con- ultants and 60 as engaged in teaching. Of the remaining ,724 engineers, 2,646 were unemployed and 1,078 were ngaged in work of a nonengineering nature.

The shifts noted in the period 1929–32, therefore, are ndicative of 2 trends affecting engineers who had been n the profession in 1929: (1) the pronounced increase in ederal employment and the decrease in private employ- nent; and (2) the comparative stability of the remaining lasses of engineering employment. These trends are ccentuated further by a consideration of the shifts which ccurred between December 1932 and December 1934.

In 1932–34, all categories of engineering employment, vith the exception of that with federal government, lecreased. Thus, an additional net total of 472 engineers raduating before 1930 were separated from private firms. The decreases in jobs in the remaining engineering classes anged from 2 in the case of teaching to 216 for independ- nt consultants. Incidentally, it may be noted that the roportion engaged in the latter class was only slightly ess than the proportion so engaged in 1929. This vould seem to indicate that the increase which did take lace by December 1932 was an artificial one. Alto- ether, the decreases in engineering employment affected 65 engineers. Despite these decreases in many types f job opportunity, there was also a decrease of 376 in the umber of engineers reporting unemployment. Only 55 found opportunities in nonengineering employment. The federal government gave engineering employment o the remaining 1,086 (87.5 per cent) of those whose tatus shifted from 1932 to 1934.

The net result of the changes in employment status mong the older engineers was such that by December 934 only 46.2 per cent were in the employ of private rms, whereas 62.2 per cent had been so engaged at the nd of 1929. Federal employment provided for 10.1 per ent in December 1934, as against only 5.3 per cent in 929. All other classes of engineering employment remained comparatively stable over the period 1930–34, especially if state, county, and municipal employment are considered together. In December 1934 there were 8.0 per cent unemployed, but it is obvious that had not 10.2 per cent of the older engineers found work of a nonengineering nature, the proportion unemployed would have been larger by that amount. It is also obvious that by December 1934 it was primarily the increased engineering employment by the federal government that ameliorated employment conditions for these older engineers.

Among the engineers who entered the profession during the depression, certain outstanding shifts may be noted. In the first place employment opportunities increased from the end of 1932 to the end of 1934 among those who graduated in 1930–32. Slightly more than half the 16.6 per cent of this group who had been unemployed or on work relief in 1932 found employment by 1934. Furthermore, they had found nonrelief engineering employment. There was no change in the proportion engaged in nonengineering work. The gain was almost equally divided between private employment and public employment. Fewer engineers were teaching or engaged in consulting work. The increase in employment by private firms, however, absorbed 5.3 per cent of all engineers in these classes. Similarly, there was a slight decline in the proportions employed by states and counties, but this was much more than offset by an expansion of federal engineering employment that absorbed an additional 5.0 per cent of the total number.

A comparison of the distributions of employment of 1933–34 graduates in 1934 may be made with employment in 1932 of those graduating in 1930–32 to show how conditions had changed as regards the most recent graduates. This comparison is not perfect because in the one case 3 graduating classes are considered and in the other only 2.

From 1932 to 1934 there was almost no change in the proportions of the most recent graduates who found engineering employment. Unemployment was slightly lower, primarily because 3.1 per cent more 1933–34 graduates

were in nonengineering work in 1934 than had been true of 1930–32 graduates in 1932.

While recent graduates in 1934 had as much opportunity for engineering employment as a comparable group had had in 1932, this was because of an expansion in private employment and particularly employment with private firms. In 1934, 4.9 per cent more of the 1933–34 graduates were employed by private firms and 1.8 per cent fewer were in teaching or acting as independent consultants than had been the case in 1932 among 1930–32 graduates.

The total opportunities for public employment were less in 1934 among the most recent graduates than had been true of a similar group in 1932. The federal government did employ 1.6 per cent more of them in 1934, but this could not offset the decline of employment opportunities with states, counties, and municipal authorities from 12.5 per cent of the 1930–32 graduates in 1932 to 7.4 per cent of the 1933–34 graduates in 1934.

The preceding discussion has shown the barriers that the depression threw in the way of newcomers to the profession. It now remains to examine the effect that even the partial absorption of the newcomers had upon the employment opportunities of the older engineers.

This interrelationship is best studied in 2 different phases of the employment cycle: (1) during a period of an absolute contraction in job opportunities, and (2) during a period of expansion. These conditions are represented, respectively, by the 2 periods 1929–32 and 1932–34. In the first, it may be recalled that total engineering employment for the adjusted sample decreased from 29,051 to 27,787. In the second period, it grew to 30,299 by the end of 1934. The adjusted data are presented in table VII.

By December 1932 employment with private firms had declined by 15.5 per cent. The loss of employment by private firms among older engineers was even greater than this. In absolute numbers, 4,530 were put out of work. Despite the enormous drop, even at this period of the depression no less than 1,522 of those engineers who entered the profession in the period 1930–32 found opportunities for engineering employment with private companies. Thus, approximately 2/3 of the loss of employment among older engineers was due to a decrease in the total amount of private employment available; 1/3 of it was due to the fact that older engineers were unable or unwilling to take employment which newcomers to the profession secured.

By the end of the second period, private-firm employment increased by 1,118 or 6.8 per cent, over that reported for December 1932. Here again there was a repetition of the condition noted for the period 1929–32. Even in this period there was a reduction in employment with private companies, affecting 472 of the older engineers. In passing, it should be noted that this decrease did not affect those who entered the profession from 1925 to 1929, but was confined to those who graduated prior to 1925. Essentially, therefore, those who entered the profession in the years 1930–34 secured all the net new employment that developed with private firms and also continued to find some openings at the expense of older engineers. Over the entire 5-year period 1930–34, although 5,002 older engineers suffered loss of employment with private firms, no less than 3,112 of the new entrants found engineering work.

A considerable number of the younger engineers were able to enter engineering activity with private firms, apparently at the expense of the older engineers. But this was probably not the result of a direct displacement on a particular job of any one group of older by younger engineers. The explanation is to be found in the relative ease with which a younger engineer found a new job as compared with an older one who had lost a job. The older engineer inevitably had a greater concern with the suitability of the employment and remuneration offered than had the man without an established position. Furthermore, the enormous influx of new entrants to the profession caused keen competition for all kinds of engineering employment, which, under the then prevailing conditions, were very definitely not of the type to suit the older engineers and which further depressed salary rates for the more elementary types of work.

The changes effected by the depression upon the engineers in the employ of state and county, and municipal and other public authorities, are in striking contrast to those which occurred among older engineers in private firms. Between 1929 and 1932 there was a 14.7 per cent increase over the total of 4,948 who were engaged by state and county and municipal and other public authorities in 1929. The increase was shared by both the older engineers and new entrants. The number of the former increased by 174, the latter by 555. By December 1934 the total so employed had increased to 5,804. But in this second period only the new entrants increased—by 228—whereas the older engineers decreased by 101, a net change in favor of the younger engineers of 127. It may be noted, however that 73 of the net number of older engineers who entered these fields of employment by December 1932 were retained.

Clearly, the older engineers in the employ of these particular public authorities held on to their jobs tenaciousl

Table VII—Increases or Decreases in Employment of Older Engineers and Younger Engineers, by Class of Employment, 1929 to 1934

(Figures adjusted as explained on page 525)

Employment Class	Total Number Reporting 1929	1932	1934	Increase or Decrease 1929 to 1932 Older[a] Engineers	New[b] Entrants	1932 to 1934 Older[a] Engineers	New[c] Entrants
All classes	27,988	28,694	32,735	−2,862	+3,568	+668	+3,373
Private firm	19,424	16,416	17,534	−4,530	+1,522	−472	+1,590
State, county, and municipal government and other public authority	4,948	5,677	5,804	+174	+555	−101	+228
Federal government	1,647	2,312	3,872	+416	+249	+1,086	+474
Nonengineering	1,969	4,289	5,525	+1,078	+1,242	+155	+1,081

a. Includes all engineers who were professionally active prior to 1930.
b. Includes all engineers who entered the profession in the years 1930 to 1932 inclusive.
c. Includes all engineers who entered the profession in the years 1933 and 1934, and also came in during this period from classes of 1930–32.

during the depression. The most marked shift as regards this type of employment was the decrease in the proportion of younger engineers who found work with such authorities. The decrease in the number of older engineers so employed by December 1934 may not have been due wholly to the increase of new entrants. Many of the older engineers may have found this employment an easier passage to federal employment, which, in the period 1932–34, required a large number of engineers as administrators and supervisors for the work-relief programs then under way. These positions may have been more in keeping with the older engineers' previous training and experience.

This last statement is substantiated by the changes which occurred in federal employment. In both periods the absolute number of older engineers who found this kind of work was greater than that for younger engineers. Thus, by the end of December 1932, federal employment increased 40.0 per cent from 1,647 to 2,312. This increase covered 665 engineers, which comprised 62.5 per cent older and only 37.5 per cent younger engineers. In the second period, the total number in the employ of the federal government increased from 2,312 to 3,872, an increase over 1932 of 68.0 per cent. The absolute increase was divided in the ratio of 70.0 per cent of the older to 30.0 per cent of the younger engineers. Over the 5-year period, the respective total absolute increases were 1,502 and 723. It was also be noted that, while in the period 1929–32 the rate of increase of older to younger engineers was 2 to 1, it increased $2^1/_2$ times for the older by the end of December 1934. From this marked preference for older engineers in federal government employment, it can only be assumed that the nature of the work did more closely meet their criteria for re-employment, at least for such opportunities as were available.

Over the 5-year period the younger engineers also had a decided advantage in securing nonengineering employment. Thus, while 1,233 older engineers were so engaged, 2,323 of the younger were able to find work of a nonengineering nature. This is made clear from an analysis of age groups of the relative increase in the number of those engaged in nonengineering to the total number displaced from engineering. The ratio of those who secured nonengineering work decreased progressively with age. Thus, 15 per cent of the displaced engineers who were over 52 years old in 1934 secured nonengineering work. The remainder were unemployed. Among those who were 28 to 32 years of age, 52 per cent secured nonengineering employment. But even the ratio of 52 for engineers entering the profession in 1925–29 was very much less than either of those for the 1930–32 and the 1933–34 engineers; for the former this was 78 and for the latter 69.

This analysis indicates that, taking all factors into consideration, between 1930 and 1934 there was a substantial net loss of employment by the engineers active before 1930, and a considerable absorption in employment of newcomers to the profession. Some of this shift may have been due to direct displacement; some of it to the securing of newly created positions by the younger men. There is no evidence bearing on the proportions affected by these 2 tendencies.

Unemployment as of February 1937

Reported by National Industrial Conference Board

THE TOTAL number of unemployed workers in February 1937 was 8,914,000, according to estimates of the National Industrial Conference Board made public April 19, 1937. This is a decrease of 203,000 (2.2 per cent) from the revised estimate for January 1937 and a decrease of 1,865,000 (17.3 per cent) from February 1936.

Employment in all types of enterprise in the United States in February 1937 as reported was 43,881,000 workers, an increase of 252,000 workers (0.6 per cent) over January 1937 and 2,457,000 (5.9 per cent) over February 1936. The number of workers employed in February 1937 was reported as 3,395,000 (7.2 per cent) below the average of 47,276,000 workers employed in 1929.

From January 1937 to February 1937 the increases reported in employment, by industrial groups, were: manufacturing, 233,000; service, 49,000; transportation, 29,000; construction, 20,000; trade, distribution and finance, 17,000; mining, 6,000; and public utilities, 1,000. The only decrease, amounting to 113,000, was found in agriculture.

Compared with February 1936, according to the report, employment in February 1937 increased 13.4 per cent in manufacturing; 7.7 per cent in trade, distribution and finance; 7.5 per cent in transportation; 5.7 per cent in the public utilities; 5.4 per cent in mining; 5.2 per cent in the service industries; 1.7 per cent in forestry and fishing; and 0.9 per cent in agriculture. The only decrease, amounting to 13.2 per cent, was found in construction.

The accompanying table prepared by the Conference Board shows the number of employed workers in the various industrial groups in 1929, February 1936, January 1937, and February 1937.

Number of Employed Workers (in Thousands) Reported by National Industrial Conference Board

Group Division	1929 Average	February* 1936	January* 1937	February** 1937
Agriculture	10,650	10,335	10,542	10,429
Forestry and fishing	268	172	175	175
Industry				
Mining	1,087	725	758	764
Manufacturing	11,073	9,518	10,565	10,798
Construction, public and private	2,841	1,387	1,184	1,204
Transportation	2,416	1,754	1,857	1,886
Public utilities	1,167	888	938	939
Trade, distribution and finance	7,323	6,751	7,251	7,268
Service industries	9,070	8,620	9,016	9,065
Misc. industries and services	1,381	1,273	1,345	1,352
Total employed	47,276	41,424	43,629	43,881

* Revised. ** Preliminary.

Police Radio Communication

By EDWIN LEE WHITE   E. C. DENSTAEDT

Synopsis

The history and development of police radiocommunication is discussed and an outline given of the federal regulations under which this type of service is rendered together with reasons therefor. The problems arising in the selection of equipment and during the installation and operation of police radio systems are discussed. The methods of operation of the various classes of police radio services are described. The various uses of radio covered by this paper are:

1. By municipalities for one-way communication to mobile units and remote police stations
2. By municipalities for 2-way communication with mobile units
3. By states in the general dispatching of state police units
4. By states and municipalities for the ratiotelegraphic exchange of police information
5. By harbor police in connection with the dispatching of harbor police boats and general policing of shipping
6. By states for emergency radiotelegraphic use in the event of interruption of the wire teletype network

Illinois state police radio station, Chicago

History and Regulation

A GENERAL study of the history of police communication systems indicates that the police of the United States have always been progressive in adapting new communication facilities to police uses. As new systems were developed they were pressed into police service to assist in the never-ending battle with crime. We thus find the wire telegraph used by New York City Police Department in 1847. In 1878 just 2 years after its invention by Dr. Bell, the Chicago Police Department installed a police telephone system. Emergency police dispatching systems with telephones for communication were in use before the automobile had replaced the bicycle and horse as a means of transportation.

Probably the first use made by any police department of radio was on June 2, 1916, when a private coastal station was established by the New York Police Department, using the call letters KUVS (now WPY) for communication with harbor police boats and for the general policing of shipping in the New York harbor. This station is still in existence, has been modernized from time to time, and is rendering a useful service.

In 1923 the State of Pennsylvania established a system of radiotelegraph stations to provide a means of communication between important police headquarters. With the growth of wire teletype communication the necessity of these stations has been greatly reduced and at the present time they are used primarily in emergencies when wire communications have been disrupted.

As far as is known the first use of radio in the manner in which we are now familiar was by the City of Detroit. Experiments were initiated in this city in 1920 when a radio receiver was installed in a police car and tuned to the broadcast station of the *Detroit News*, the only broadcast station in the city at that time and one of the first in the country. The result warranted further investigation and in 1921 a station was established using the appropriate call KOP.

The early Detroit experiments although partially successful, did not immediately result in a radio equipped police department. The cumbersome receivers and fragile tubes available at the time resulted in unreliability and a high cost of maintenance. However, in 1924, a regular broadcast of stolen automobiles and crime reports was inaugurated, primarily for the use of outlying police departments in the Detroit area.

During the next few years sporadic tests and experiments were made along various lines with a view to determining the most suitable manner of fitting radio into police department needs. For instance, about 1924 the City of New York conducted experiments and purchased some equipment for station house use with a view to establishing a system which would permit, by the use of a suitably designed dial call system, the transmission of a message to all stations simultaneously, to an individual receiver, or to a selected group of receivers.

The early experiments were conducted on the band of

A paper recommended for publication by the AIEE committee on communication. Manuscript submitted March 17, 1937; released for publication March 25, 1937.

EDWIN LEE WHITE is senior radio engineer for the Federal Communications Commission, Washington, D. C. E. C. DENSTAEDT is a lieutenant, and supervisor of radio, in the police department of Detroit, Mich.

frequencies now assigned to the broadcast service. With the growth of broadcasting it became evident that it would be necessary for a separate band of frequencies to be assigned for police activities. This situation resulted in the allocation of 8 frequencies between 1,700 and 2,500 kilocycles by the Federal Radio Commission, which were set aside for use by state and municipal police departments without distinction.

The development of the screen-grid tube and discovery of methods of reducing ignition interference simplified technical difficulties and in 1928 the first successful radio patrol was inaugurated. The remarkable success of this patrol caused the system to spread rapidly. Several cities added this equipment in 1929 and 1930. In 1931 the State of Michigan installed a 5-kw transmitter at Lansing to serve those cars of the Michigan State Police which operated over the lower Michigan peninsula.

At the time the Federal Radio Commission made its first allocation of frequencies it did not appear that specific provision of radio for state police would be a particularly serious problem. However, it quickly became apparent that the allocation of frequencies to municipalities must of necessity be carefully considered and the issuance of authorizations closely co-ordinated if radio facilities were to be made available to all municipalities throughout the country.

It was determined that any plan of allocation must meet the following conditions:

1. It must provide for the issuance of authorizations to any municipality regardless of its location within the United States, or the status with respect to radio of adjacent municipalities.

2. It must be capable of administration in congested areas, such as Philadelphia, Chicago, and New York as well as in sparsely settled districts such as Nevada.

3. Considering the number of frequencies available it must provide the maximum service with the minimum of interference.

In the consideration of the establishment of a system of allocation of frequencies the following principles were used as a basis:

1. It is not necessary that the police cars receive a high quality of service, as long as signals are sufficiently intelligible through interference to ensure accurate reception they are satisfactory.

2. There is a higher incidence of crime in densely populated areas than in sparsely settled districts. Consequently, more messages per thousand population would require transmission in large cities than in rural areas.

3. The poor transmission conditions of the congested areas and the level of electrical noise in such areas require more watts per mile than in the rural districts.

Considering these factors and after much study the United States was divided into areas, the size of the area depending upon the population to be served as well as the density of population. For instance, for all practical purposes the cities of New York and Chicago embody single frequency allocation areas while the whole state of Nevada likewise embodies a single allocation area. Under this plan all cities within a single area are required to co-operate in the use of the area frequency. The power is in general limited by the total population to be served. In order to limit interarea interference a maximum power limitation of 500 watts night, 1,000 watts day is placed on these stations.

It is desirable for adjacent municipalities to pool their radio activities. Provision was, therefore, made for the establishment of a station to serve a number of municipalities and the authorization of power necessary to serve the total area, provided that an agreement was submitted with the application for increased power showing the establishment of a metropolitan area type of system.

Referring again to the frequency-assignment problem, in 1933 as a result of a regional international conference held in Mexico City, frequencies were made available for police use by international agreement. At this time a general readjustment of municipal police area boundaries was made and in addition provision was made for the establishment of state police radio stations. A specific frequency was allocated for the use of the state police of each of the 48 states without reference as to whether the state was at the moment contemplating either the establishment of a state police or of a state police radio system.

Referring to figure 1, which gives the present allocation of frequencies to states, you will note that on an average each frequency is shared among 4 states. The frequencies allocated by the Mexico City conference have been, by agreement with Canada, further allocated as among the United States and adjacent nations. The allocation plan shown in this figure gives due weight to this situation and it is possible for Canada, Mexico, Cuba, and other countries adjacent to the United States to establish police radio stations in the recognized bands for such service and to receive the same quality of service as is rendered by these stations as established in the United States.

Figure 2 shows the existing plan of allocation of frequencies to municipal police stations. As in the case of the state police service shown in figure 1, the allocation shown in this figure also makes provision for the establishment of police stations in foreign countries.

Perhaps the most important effect of the use of radio has been in the growth of a co-operative feeling by the various police agencies of the nation. Possibly because of the necessity for co-operation in the use of radio frequencies a general feeling of co-operation has grown until at present every police officer is willing to give and anxious to receive all possible information which may be available with regard to crime in any adjacent locality.

In line with this co-operative feeling a need was felt for point-to-point communication between police departments. As a result many cities began exchanging communication at night using facilities allocated primarily for communication with mobile units. The service was found to be valuable and resulted in the rapid solution of many crimes which might otherwise have gone unsolved or have had the solution delayed for an extended period.

Approximately 2 years ago the organization "Associated Police Communication Officers" was established and practically the first action of this organization was to recommend to the Commission that steps be taken leading to the establishment of a police radiotelegraph communication system designed to meet the need of police departments for a means of exchanging information. After a

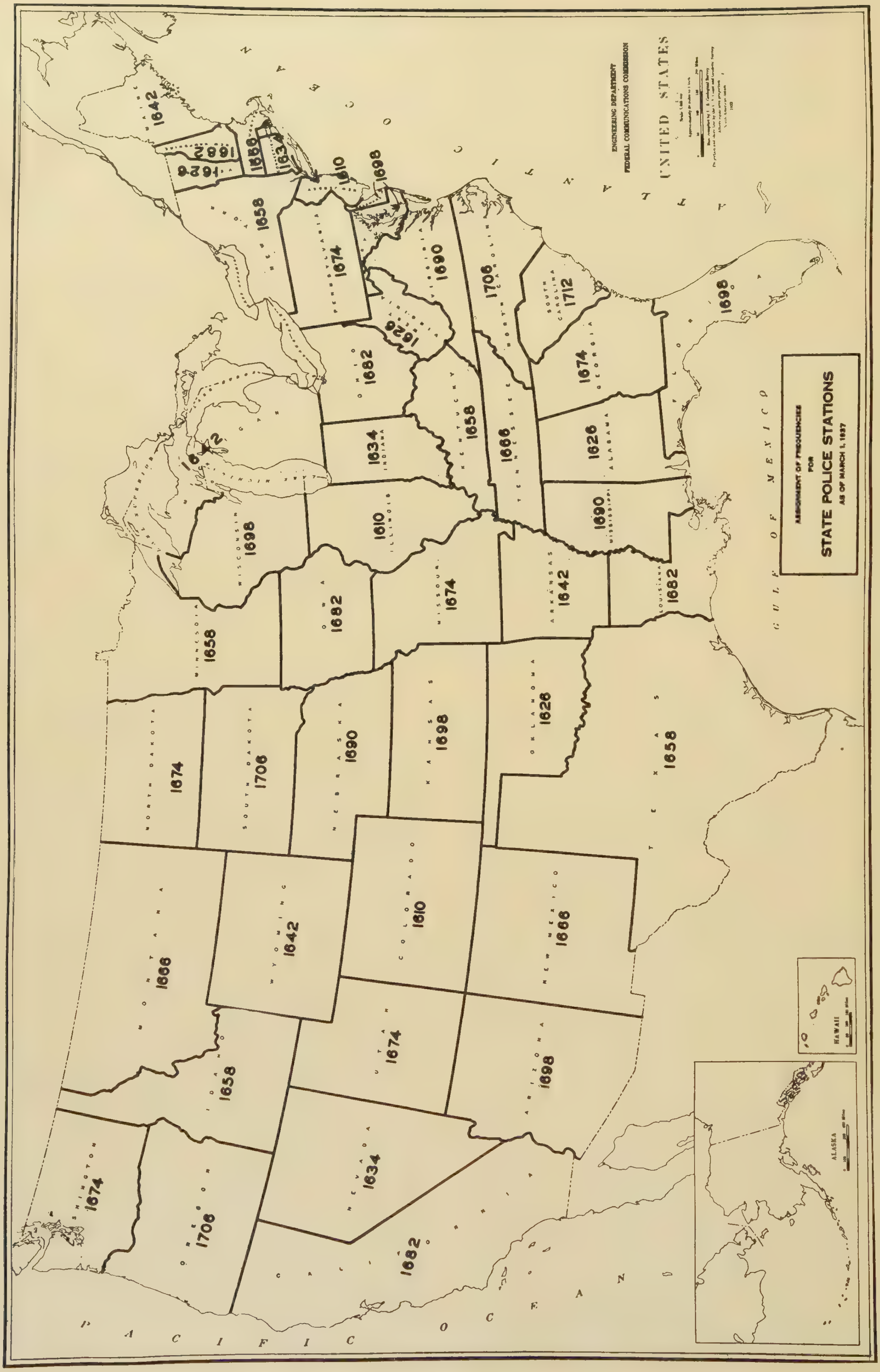


Fig. 1. State police frequency allocation plan as of March 1, 1937

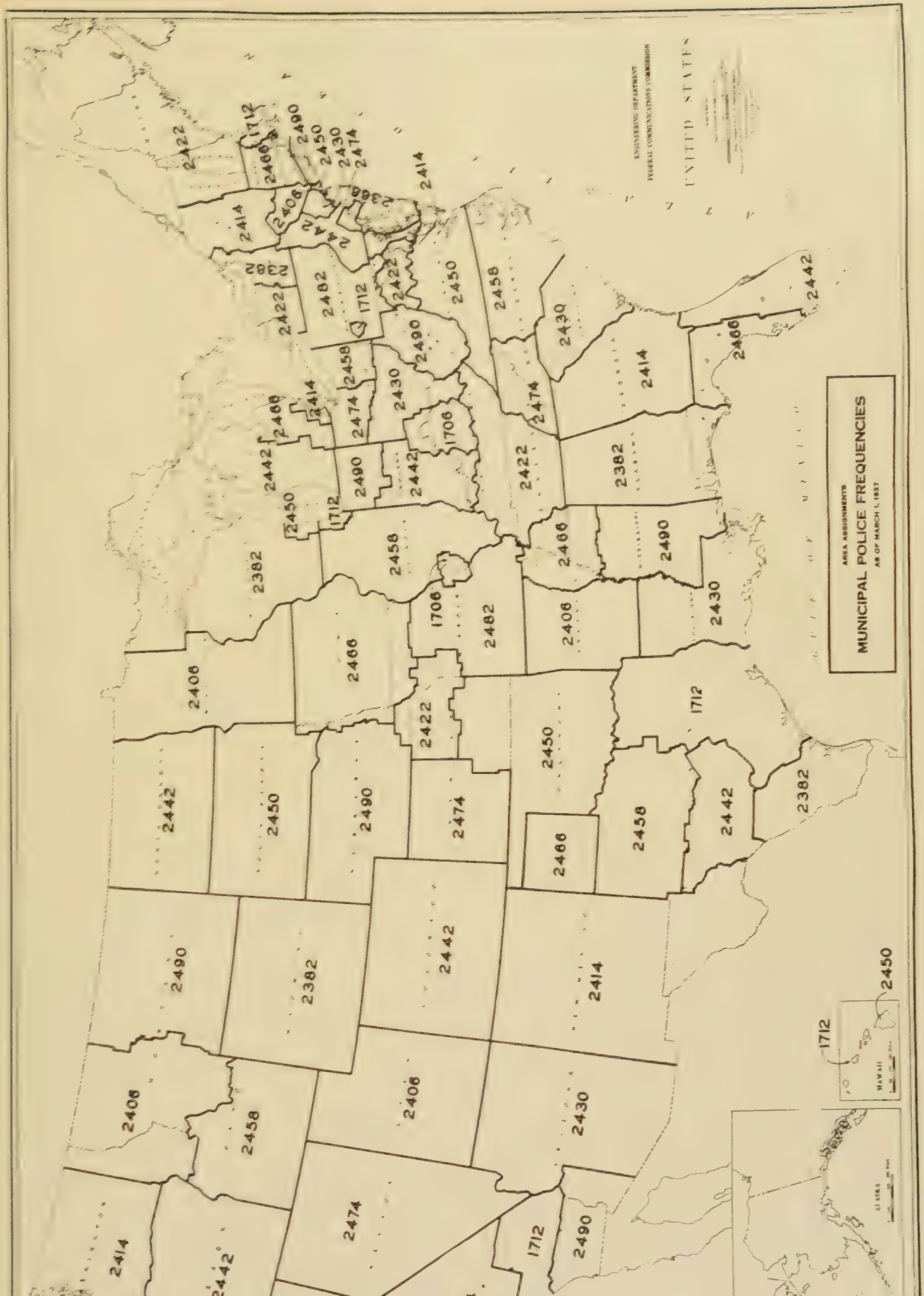


Fig. 2. Municipal police frequency allocation plan as of March 1, 1937

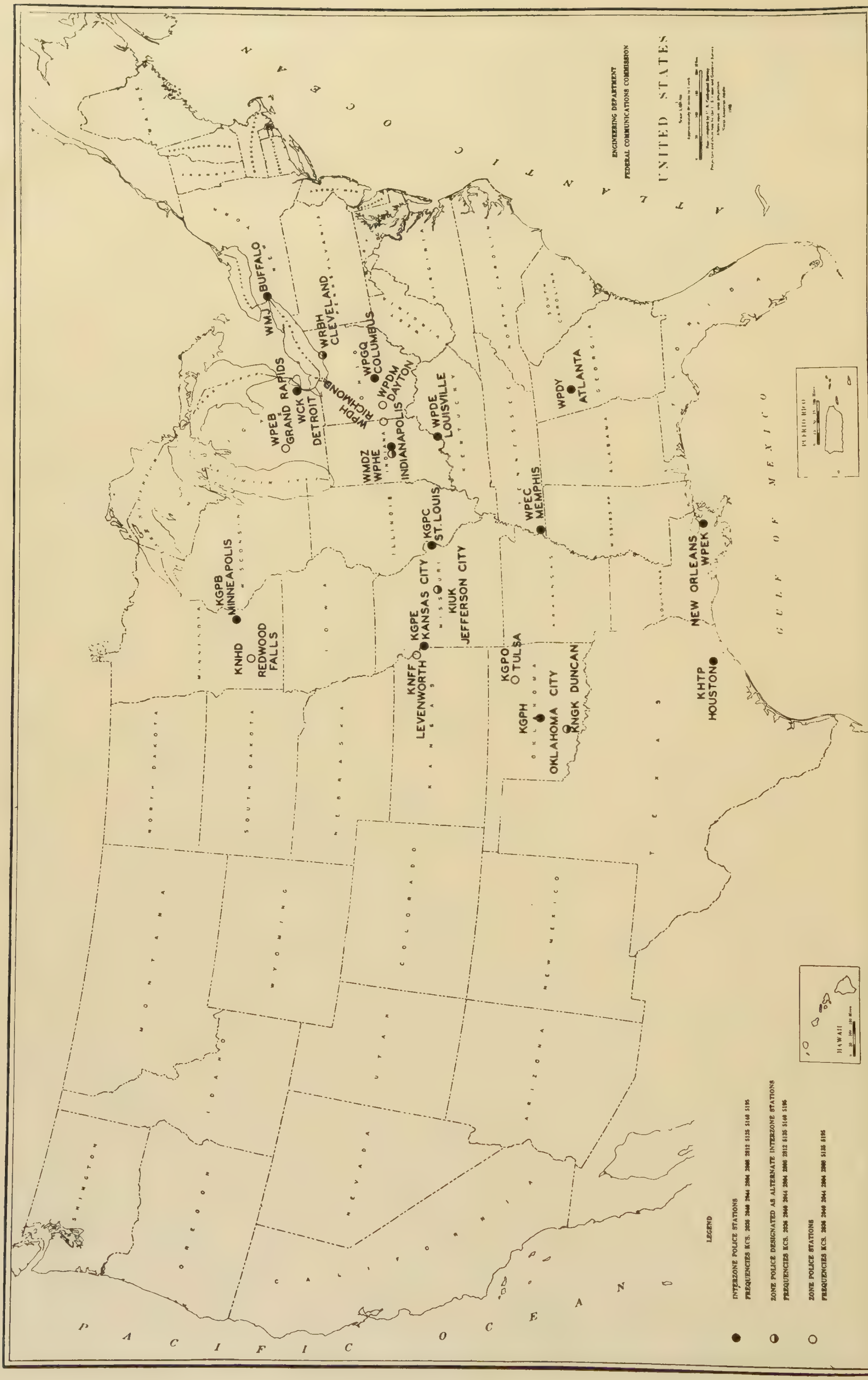
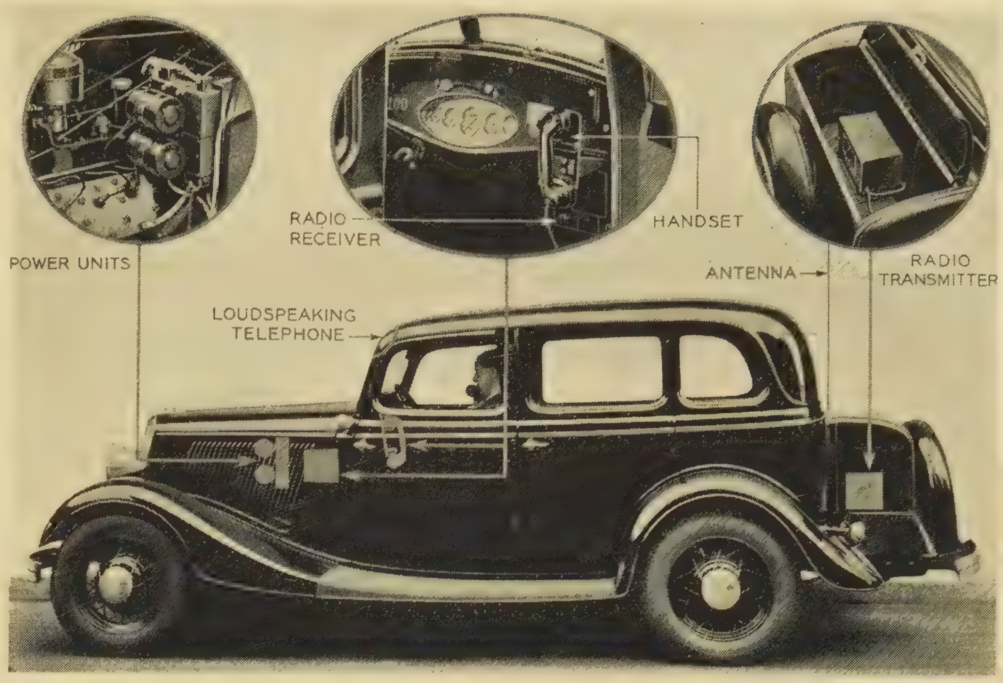


Fig. 3. Stations authorized in the intercity radiotelegraph system as of March 1, 1937

An automobile equipped for 2-way police radio communication

The system is operated on ultra-high-frequency channels. The transmitter weighs 20 pounds, has a power output of 5 watts, and its frequency is crystal controlled. To talk from the car, the patrolman merely lifts the telephone from the instrument board and the first sound of his voice puts the car's transmitter on the air. It switches off automatically the instant he ceases talking. The transmitter uses 4 pentodes; the receiver is a 6-tube heterodyne



Western Electric Photo

co-operative study in which not only the Communications Commission but also the police, the Army, and the Navy participated, a system has been established and is now in operation. It is based primarily upon the type of communication system employed by the military services. The same general procedure is used and the same type of control of communication is required.

Under this system the United States is divided into zones, each of which is under the jurisdiction, as far as the use of radio facilities by zone police stations is concerned, of a zone control station. In general, under the supervision of the zone control station, municipalities within the zone are permitted to exchange messages freely with each other. However, messages from zone to zone must be routed through the zone control stations involved for final dispatch. Figure 3 shows the extent to which this system had grown on March 1, 1937. A number of stations have been added since this illustration was prepared.

The Commission will continue its policy of co-operation with the using service in order that modifications may be made from time to time to best fit this new instrument to the hands of police officers.

A few years ago the frequencies above 30,000 kilocycles were deemed to be practically useless. As a result of the activity of amateurs in the band between 56,000 and 60,000 kilocycles it was demonstrated that these frequencies could be quite useful for many types of local communication. The Commission then received requests from certain police organizations for authority to establish stations for use by their police departments on frequencies in or adjacent to the amateur band. After considerable study and consultation with those interested and well informed with regard to the propagation characteristics of the frequencies above 30,000 kilocycles, the Commission authorized 4 frequencies lying between 30 and 40 megacycles which might be licensed temporarily to general experimental stations which were to be operated as municipal police stations. Although licensed experimentally, from the point of view of the police officer in the car these stations were not experimental since they were used for the regular dispatch of police officers in the same manner as if a regular license had been granted. They might perhaps be considered as units in a program of experimental research conducted by the Commission to determine the frequency in these bands best suited to police departments and to determine a number of other engineering questions such as the total number of frequencies necessary to serve the police, the mileage separation which must be maintained between assignments of identical frequencies, and the frequency separation which must be maintained between adjacent channels.

On the frequencies assigned to municipal police stations the establishment of 2-way communication between the police officer in his car and police headquarters has always been prohibited for various reasons, some of which are technical. However, the use of frequencies above 30,000 kilocycles offered an opportunity for the establishment of a 2-way communication system. Although initial installations on these high frequencies were identical in all respects to those on frequencies used by municipal police stations, very quickly a number of municipalities began the experimental use of 2-way police communication. The first authorization issued by the Commission for 2-way police radiocommunication was to the city of Bayonne, New Jersey, on December 22, 1932. On March 1, 1937, 226 cities were operating 1,367 mobile police transmitters providing for such 2-way communication. Of this number of cities 22 made new installations after January 1, 1937.

The experimental program of the Commission on frequencies above 30,000 kilocycles has practically completed one of its phases. On June 15, 1936, the Commission held an informal engineering conference at which time the needs of all the various services were discussed with particular

respect to their needs in the band of frequencies above 30,000 kilocycles. As a result of this hearing allocation plans have been studied and in the near future routine commercial licenses will be issued to various stations to replace experimental licenses outstanding.

Installations and Equipment of Municipal Police Systems

The installation of police radio equipment in a city is essentially a radio-engineering problem but it is unusual for it to be handled upon a strictly theoretical basis, a compromise generally being made between the ideal and the most economical arrangement. A preliminary survey usually is made to determine if present city owned property or buildings are in a favorable position for a transmitter location and also contain the necessary connections to the police telephone system. Since the average police department has a number of precinct stations, all of course connected into the police wire system, it is generally possible to pick out a building that is in the proper geographical position with respect to the city boundaries and also not in too unfavorable a transmitting location. In 4 cities it has been found necessary to use more than one transmitting station to give adequate coverage. In those cases the transmitting locations cannot be decided upon by considerations of the territory each is to serve alone but also must be considered with respect to one another as well.

In some cases cities have been able to gain some of the advantages of an open location by erecting the transmitting station in a park within a few miles of the district in which a heavy field is desirable. In other cases transmitting stations have been erected in residential sections composed mainly of small homes and fairly clear of large buildings.

In the majority of the early police radio installations the equipment was of composite manufacture. At present, however, radio manufacturers are offering equipment that fits this field and the average installation today uses commercial equipment.

Police radiotelephone transmitters are in general designed for good speech reproduction, but do not need the high standards of fidelity that are built into modern broadcast transmitters. The relay and switching systems must be very sturdy, however, since some of these transmitters are turned on and off over 1,000 times in 24 hours. Standby voltages must be maintained upon the filaments and if rotating equipment is used it must run continuously, it being desirable to have those transmitters come on the air with a delay of not more than one second.

Since the transmitters are used primarily for emergency transmissions, delay in a message becomes serious and it is necessary rapidly to repair the transmitter. To avoid delay a number of cities have installed standby equipment.

The usual troubles encountered are tube, relay, or control circuit failures. Regular inspection and maintenance can reduce the relay and control circuit failures to a minimum.

Fixed receivers at stations offer no particular problems in municipal installations. Antinoise-type antennas are often necessary because of the electrical disturbances originating from call box and teletype circuits in the precinct stations. A simple doublet-type antenna with a twisted pair lead-in is usually satisfactory in such installations.

Automatic volume control may or may not be an advantage. The particular location at which the receiver is to be placed should be studied with respect to this factor. If the station is in an area having a low field strength it may be necessary to use automatic volume control in order to insure reception during periods of low signal. However, in such circumstances a carrier operated antinoise device should be embodied in the receiver in order that the occupants of the station house may not be annoyed by atmospherics and other forms of interference during the time no signal is being received.

The important thing in station receivers is to obtain equipment designed for continuous service. Most cities are using receivers designed for the job and are experiencing little trouble.

The mobile-unit receivers are, however, a different story and practically every department can furnish many woeful tales about their experiences. Troubles with mobile installations are divided between those caused by car ignition, battery, or antenna and those in the receiver itself.

Troubles in mobile police radio receivers are much more numerous than those experienced in broadcast receivers for automobiles. Police re-

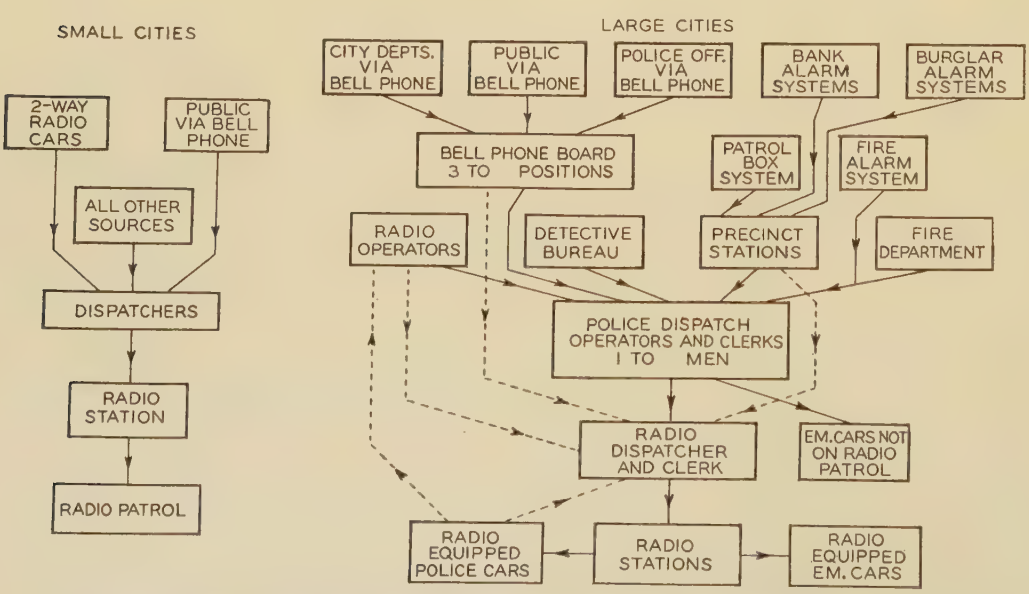


Fig. 4. Routing of emergency messages in police departments

ceivers operate 24 hours a day and are mounted in cars that will drive 50,000 to 75,000 miles in a year. Several attempts to modify standard broadcast auto receivers so as to be used in police cars have resulted in disappointment and today the great majority of police departments gladly pay the increased cost necessary to obtain receivers manufactured for police service.

Tube life in police mobile receiver service is now very good, particularly when the cars are equipped with voltage regulated generators.

A life of 1,000 hours is often used as a standard for tubes and vibrating equipment in radio work. While this may represent a life of over one year in ordinary passenger car service, it only represents a life of 6 weeks in police service.

The great majority of police receivers in service use dynamotors for B supply, a few using vibrating rectifiers. In general better life has been experienced from the dynamotor and it, in spite of its greater cost, is in greater use.

The detuning or drifting of police receivers, once the greatest single source of trouble, has been fairly well taken care of as far as municipal police work is concerned. State police organizations, however, needing greater sensitivity and selectivity in their receivers, are still experiencing trouble. In some cases recourse has been made to the use of crystal-controlled receiving equipment.

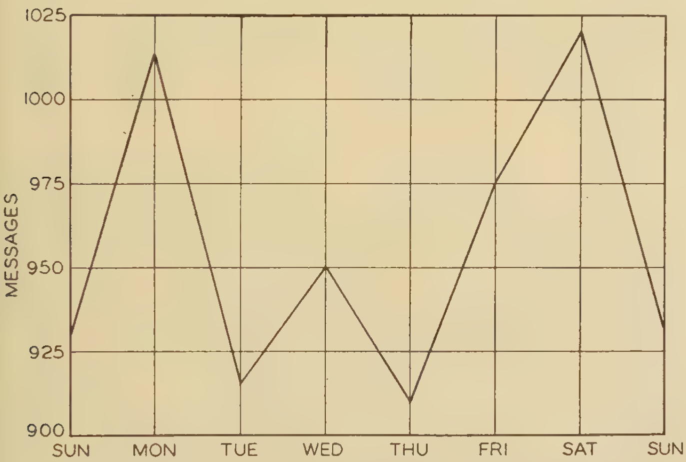


Fig. 5. Average daily load chart of a representative municipal police radio station

The average police receiver draws from 4 to 7 amperes from the car storage battery. This drain when continuous and coupled with the fact that police cars cruise slowly would result in discharged car batteries unless special provision is made. Standard generator and battery equipment on automobiles has proved to be inadequate for police radio service and special voltage regulated generators are generally installed on cars for municipal police patrol.

The generator used should be able to balance the radio and ignition load on the car battery at the slowest cruising speed of the cars, usually about the slowest speed at which the engine runs evenly. This varies from 6 to 10 miles an hour. The generators should peak at a speed between 15 and 20 miles an hour and should have a peak current of from 18 to 25 amperes. They must be equipped with a voltage regulator. Such generators are now commercially available.

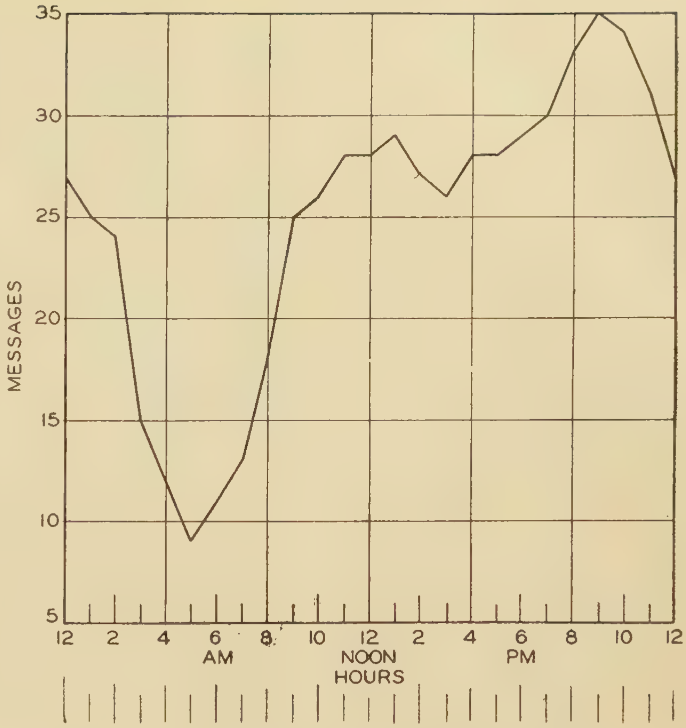


Fig. 6. Average hourly load chart of a representative municipal police radio station

It is also considered desirable to advance the battery size in municipal patrol cars in order to carry over periods when it is necessary to leave the radio on but the motor off. Such cases happen quite frequently when car crews are "planted" to watch a car or house.

A screen antenna in the top of the car had proved to be the most satisfactory antenna for police radio work. However, with the advent of the steel top, police were forced to use various forms of undercar antennas, none of which are entirely satisfactory. A better antenna is provided by use of an insulated steel rod rising from the dash, either straight or curved back over the top. The rods, or "fishpoles," are flexible and no harm results from their hitting something.

The reduction of electrical noises set up by the ignition system is accomplished in much the same manner as is standard with broadcast receivers but, because of the higher frequencies used, it is a slightly harder job. Standard spark-plug resistors together with condensers on generators, gas, and oil gauges are used, bonding and shielding are carefully installed. If after an installation is made it is found that ignition noise remains at a high level, different things are tried until the noise is eliminated. As a general rule spark-plug resistors are kept as low in resistance as it is possible to use, since resistors of 25,000 ohms and up have caused some engine trouble.

Some police car receivers have a sensitivity control as well as an audio volume control to take care of the "carrier off" condition. If the sensitivity control is retarded sufficiently to reduce the electrical noise at points

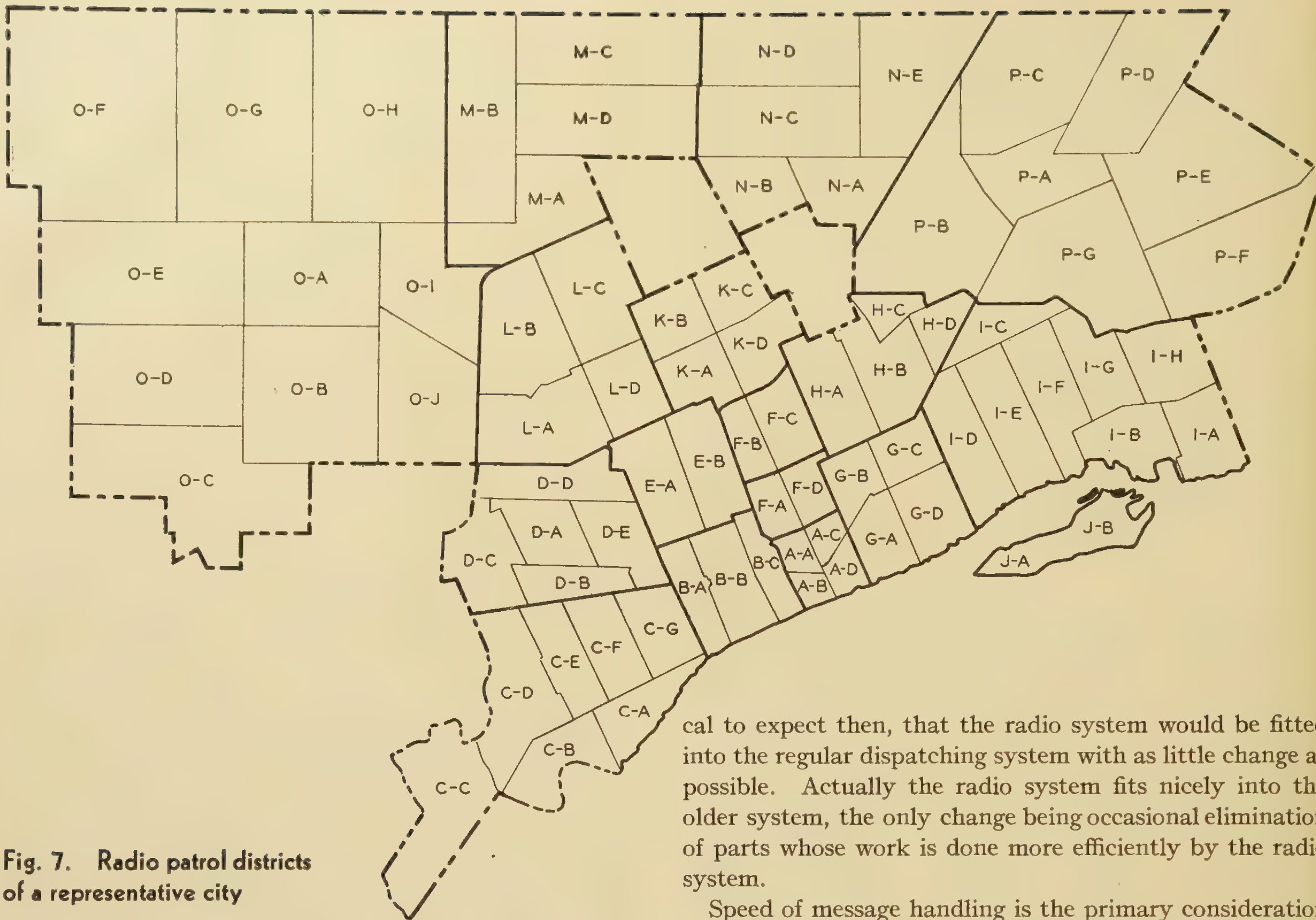


Fig. 7. Radio patrol districts of a representative city

in the city where electrical noise levels are high it may also automatically cut out the signal because of the relatively weak radio field from the police transmitter, a dangerous condition in police work. Antinoise circuits have aided in reducing the noise but at best police receivers in patrol cars on busy streets several miles from a transmitter, are rather noisy.

The crews of police cars shade into 2 general classes. One group who keeps the controls turned up and seem oblivious to the noise, the other who keeps the control retarded so much, that when street noises are high they have to turn up the volume to understand the broadcast. Observations indicate that this second group senses the presence of the transmitter carrier by the change of the background noises in the receiver, and, therefore, seldom miss any broadcast information due to the practice of carrying the receivers at low volume settings.

There are some types of men, usually of a nervous disposition, who should not be put on radio patrol cars. The combinations of noises, mental strain due to the presence of a receiver which at any moment may reproduce an order, and the lack of physical exercise have a bad effect on their health. In one of the larger cities the police medical division is at present quite concerned over the problem.

Operation of Municipal Police Systems

The police radio system is simply a development and extension of previous communication systems. It is logical to expect then, that the radio system would be fitted into the regular dispatching system with as little change as possible. Actually the radio system fits nicely into the older system, the only change being occasional elimination of parts whose work is done more efficiently by the radio system.

Speed of message handling is the primary consideration involved, and of course, a system whereby the person wanting emergency police assistance could call directly to the policeman coming to his assistance would be the ideal method. Obviously this is impossible, yet in smaller towns only 2 intermediate persons are involved, one the telephone operator who makes the connection, second, the police dispatcher who sends the help, figure 4*A*. In the larger cities this simple system, although just as desirable, becomes impossible because of the volume of the traffic. It becomes necessary to set up a system similar to 4*B* which, while it may look complicated, is as simple as it is possible to arrange and still have a system that will operate smoothly and with rapidity during peak periods.

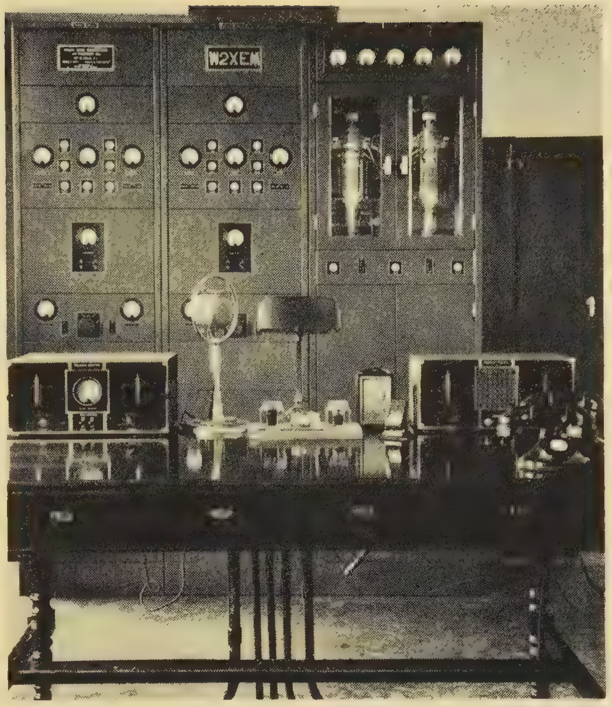
Figures 5 and 6 show the average load charts of a representative police radio station. Actually these average peaks are increased considerably upon such evenings as Hallowe'en, New Years Eve, etc.

The sources of police information of all natures are extremely numerous, however, the sources of information requiring emergency action are fewer in number. While the detective bureau is shown as a source of information in diagram 4*B* the reference is to emergency cases only which are a small part of their activity.

By far the greatest number of emergency requests comes from the public over the telephone system. The incoming telephone switchboard in larger cities thus has to be used in multiple sections so as to allow any one of a number of operators to answer any incoming trunk line. In some cities all incoming calls come in on the one board, in New York, however, emergency calls and routine calls are seg-

regated by having the public call one telephone number when emergency service is desired, and another when making routine calls. Each board, of course, can handle emergency messages in cases where the public makes a mistake.

The switchboard operators handle all routine calls much as any telephone operator. They are trained, however, in proper handling of an emergency call and in how to get the most information from an excited person, and get it reliably. At best the information is none too accurate. The operators then pass this information along to the dispatchers who either broadcast the necessary order or in the largest cities pass it on to another man for broadcast.



Transmitting equipment of the Newark, N. J., police radio system. Duplicate transmitters, one of which is a stand-by unit, are provided. The unit at the right is the power amplifier, which may be fed by either of the other sets

The dispatcher's board besides receiving information from the general board may get information from several other points as noted in 4*B*. Bank alarm systems usually are terminated in precinct stations, sometimes in headquarters; fire-alarm systems also occasionally have a wire into the police department and policemen are dispatched simultaneously with fire equipment. Other sources of information include police, via the patrol-box system, precinct stations and substations, radio operators, and fire and other city departments.

It will be noted that the dispatcher has other facilities besides the radio patrol at his disposal. Patrol wagons and other emergency vehicles are kept at precinct stations and substations, and ambulances, pulmotors, etc., at other points. He decides as to what vehicle is to be used, dispatching it or passing the information to the person who makes the dispatch as the case may be.

The dotted lines on diagram 4*B* indicate routes taken by messages of 2 general types. First: routine unimportant traffic with which it is not desirable to load the dispatcher since the emergency dispatch is not involved; second: exceptionally important or "hot" information which must be transmitted without the slightest delay. Most systems are flexible enough to allow some deviation from regular routine in particularly important cases.

The majority of cities have centralized the dispatching authority into the dispatchers. These men and no others are responsible for the proper dispatch of policemen to the scene of a crime, fire, or disturbance. In some cities the dispatcher's word is absolute law in all precincts, and the commanding officer of a precinct cannot move a single emergency vehicle in his own precinct without permission of the dispatcher. This of course means that the dispatcher in addition to being a good police officer, must be familiar with the city, must know the territories patrolled by each car, and must have a continual accurate check upon the condition of each car. The dispatcher is often assisted by a clerk, while various check boards, maps, mechanical or electrical arrangements are used to keep track of the cars. The dispatcher must know where his cars are at all times, whether they are in or out of service, when they are on a run, and when they need radio or garage service. To the dispatcher and his assistants is delegated the job of keeping track of a large fleet of cars. This job is made harder by the fact that these cars are continually prowling about the city doing routine police work on their own initiative while waiting for emergency broadcasts or specific orders. The details involved in this position are considerable and a mistake may mean a missed run or possibly a lost life.

Messages broadcast by police radio stations fall into 4 general types:

1. Emergency dispatches: Orders to a particular car to proceed to the scene of a crime, fire, or disturbance. This is the most numerous and most important of the 4 types of messages

2. General broadcasts: Crime reports, stolen cars, missing person reports, descriptions of wanted persons, etc.

3. Station calls: Routine police work, orders to cars to call their stations, go for gasoline or repairs, take care of a detail or traffic, etc.

4. Intercity traffic: Messages of police nature transmitted to other police radio stations by radiophone

The police radio station exists primarily for broadcast of types 1 and 2. Type 3 is more or less routine and is handled if time permits, while type 4 is not handled at all by some cities. It is expected that police radiotelegraph will eventually handle most of this latter type of traffic.

An interesting point to note here is that because of the general unreliability of information coming from the public, very often a broadcast of type 1, sending a police car to the scene is made before a general broadcast of the crime (type 2). The actual descriptions, etc., are obtained by a policeman from the persons at the scene.

In municipal one-way systems the patrolmen, after having been sent on a run, call back over the police or city phone systems. The dispatcher or radio operator de-

pends entirely upon the car crew hearing the run and obeying instructions. If, however, the car crew does not report back in a specified time after the order is broadcast (from 5 to 30 minutes depending on the city), another car is dispatched.

No system is perfect and occasionally a run is missed. A follow-up is desirable on important runs, therefore, 2 or more radio cars are often sent. In some cities station cars are dispatched by telephone in addition to those dispatched by radio.

The efficiency of the radio equipment is attested by the fact that accidents, car failure, and mistakes made by the operating personnel each result in as high a percentage of runs missed as does failure of radio. Radio failure as a cause of missing runs is of course eliminated by the use of a 2-way system and most larger cities are now experimenting with 2-way equipment. In a 2-way system if the dispatcher does not get an immediate "OK" from the car crew dispatched, he dispatches another car.

As the radio system follows the plan of the precinct signal systems, so are the territories of the radio patrol cars influenced by the precinct boundaries. Each precinct is broken up into patrol territories and a radio patrol car assigned to each. In addition there may be other cars, usually better equipped and carrying a larger crew, who patrol through the whole precinct or through several territories and still other crews and cars that work more or less free lance or on special police problems. Each territory and car are assigned a number and this number alone is used in dispatching. Often individuals are assigned numbers to permit their being called without mention of names.

Figure 7 is a representative layout of the city of Detroit (neither correctly numbered nor accurate) that shows how cars may be arranged in a large city. In this case the actual car numbers are replaced by letters that have no significance.

The patrol districts are chosen systematically with the following factors in mind:

1. Density of population

2. The crime record of the territory under consideration

3. The traffic problem, in which account is taken of the density of traffic, of possible congested points, and of impediments such as railroads, canals, etc. The traffic problem affects the speed of police cars, and therefore, the time required to respond to a call.

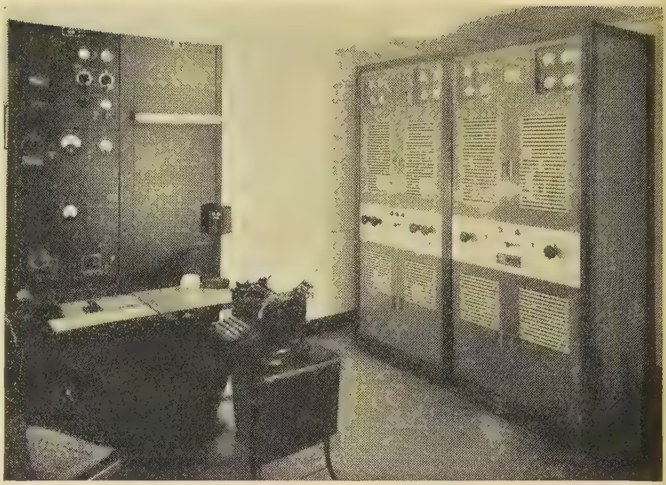
4. Other police protection. (Such as detectives, traffic officers, etc., in the business sections)

5. Records of the radio station as to the frequency and number of runs originating in the territory considered

By this mehod the available cars are placed where they will result in the most effective patrol.

Two-Way Police Radio Systems

It seems unnecessary to justify the additional expense of the 2-way system, yet a number of departments have been hampered in obtaining funds for installation of 2-way equipment because of the fact that they have a one-way system in successful operation.



A view of the equipment at station WRDP, of the Michigan state police, located at Paw Paw

Certain types of crimes can be solved in many cases if rapid efficient communication can be maintained between the police dispatcher, or radio operator and a crew on the scene. This refers only in part to continuous pursuits, where other cars can be used to block off escape. These are spectacular and have attracted press notice but more important are the cases where information immediately furnished by the car crew on the scene results in a broadcast and a capture by another car crew before a clean getaway can be made. In hit-and-run cases it is often possible to obtain a hit-and-run license number from a crew on the scene, check registration and have another car waiting at the driver's home when he gets there. Since only a few minutes are available, by eliminating the time required for the patrolman to get to a phone and get a connection to the dispatcher or radio operator, 2-way often means the difference between success and failure. Seconds count in police work.

Two-way radio makes the patrol force more efficient. The efficiency of a police department depends considerably upon attention to details. Routine and uninteresting though they may be, they are important. As an example, a patrol car crew passes a parked car, something about it makes them slightly suspicious, if the patrol car is equipped with 2-way communication, in such a case they would call for a check on the license and sometimes find their suspicions are correct. Only once in 100 times possibly, but that once may be extremely important.

Consider now, that the cost of a 2-way system is but a fraction of the yearly salary cost of the patrolmen assigned to radio cars and we see why 2-way growth has been rapid.

Two-way radio systems divide into 2 types, one using ultrahigh frequencies exclusively, the other using a medium high-frequency station transmitter. Cities which are making an initial installation of a complete system now usually install the first type. The second type exists in those cases where cities already equipped with a one-way system add ultrahigh-frequency transmitters to their mobile equipment. There are also certain situations in which

installations of the second type are made due to the fact that the municipality involved has assumed responsibility for the rendition of service to surrounding areas, such as the county, which lie beyond the range of any ultrahigh-frequency transmitter which could be considered.

The method of operation of 2-way systems also varies and can be classified as follows:

1. Simplex operation: One frequency is used for both station and car transmitters. Only one can be on the air at a time, direct car-to-car communication, when the cars are not separated too far, is possible

2. Duplex operation: The station transmitter is on one frequency, the cars on another. Both can talk at once if necessary and operation is similar to ordinary telephone conversation. Car-to-car communications not possible except by rebroadcast through the fixed station (sometimes called triplex)

3. Voice break-in operation: A system using voice operated relays that control transmitter and receiver. In this case one station can break in on the other during pauses in speech. Direct car-to-car communication is also possible in this method under the same conditions as specified in the first case.

In its actual operation the 2-way system does not differ greatly from the one-way system. Calls are received and handled as noted in figure 4. The difference is that return calls from the car crews are made by radio instead of wire. The dotted lines in figure 4*B* from patrol car to dispatcher or radio operator indicates this communication channel. The only possible addition is direct car-to-car communication, which is not shown in the figure.

State-Wide Radio Systems

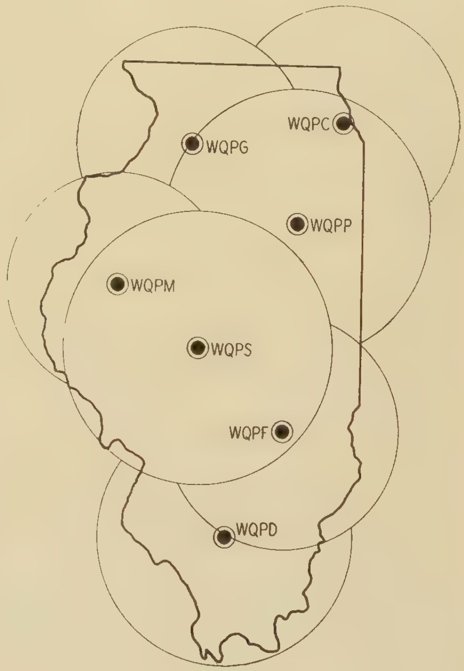
The last few years have seen increasing interest in statewide radiotelephone systems and, while state-operated systems are not as yet in operation in the majority of states, the time is not far away when they will be. In some states teletype systems are used while in others a state patrol force does not exist. Parts of states are sometimes given the benefit of radio coverage by arranging with municipalities having transmitters for broadcast of necessary messages, all of which tends to delay state police installation.

The engineering problem involved in the installation of a statewide police radio system differs considerably from that in the municipal police system. Electrical noises, shadows of steel buildings, and high noise levels at certain points provide the major problems in the selection of a site for a municipal police station. However, the problem involved in a state police system is primarily the size of the area to be covered and the average conductivity of the ground within that area. The problem is so involved that it is doubted the selection of the most economic facilities can be based on anything less accurate than actual field strength surveys.

It is characteristic of the frequencies used by state police radio systems that at a more or less definite distance from the transmitter, depending upon the conductivity of the ground pronounced fading occurs which is usually sufficient to make the signals practically useless. Increase in power will not obviate this difficulty The distance at which this so-called fading wall appears is dependent upon the conductivity of the ground and the type of antenna in use. On the basis of a field-strength survey the location of the fading wall can be quite accurately determined, as can the amount of power necessary to place the minimum useful signal at the inner edge of the fading wall. The use of any power beyond this figure is wasteful. Thus some states have found from 3 to 7 transmitters necessary. Figure 8 illustrates the arrangement of the stations in the state of Illinois. This arrangement was determined on the basis of a field strength survey. The circles shown indicate the 100-microvolt contour which was estimated to be the inside boundary of the fading wall or the maximum range at which satisfactory service might be expected. At the present time it is possible to operate the cars at a considerable distance beyond this range.

In selecting transmitting locations for municipal police stations it is the usual practice, as stated above, to select city-owned property as a site for the transmitting station. However, in a state system it is often found economical to purchase new property, erect new buildings, and move existing state police headquarters to the location best

Fig. 8. Arrangement of state police radio stations in the state of Illinois, showing coverage of each station



suited for radio transmission. In selecting this location the primary factors to be considered are:

1. The most suitable location for statewide coverage with the minimum number of stations

2. The location of the property as nearly as possible to a highway network center

3. Availability of commercial power and wire communication circuits

The use of a number of transmitters for state police service has an advantage in addition to that of pure economics. Many of the situations that arise requiring the transmission of a message over state police radio stations are of restricted interest and may be handled by the local station. Each of these stations then becomes a unit in a statewide

system and each has its own sphere of activity. This feature results in a strengthening of the patrol, since in major crimes or statewide man hunts all departments act together, usually under the direction of one of the state stations. It may also provide a local police radio service to the county sheriff's officers, or the small communities that would of necessity be unable to afford a system.

Many states are providing, in addition to stations at fixed locations, state police stations located in trucks that can be moved to scenes of disturbance or disaster to operate with a temporary state police headquarters in order that the greatest facility may be had in handling the situation. The utility of this type of installation was amply demonstrated during the recent flood, in which the State of Ohio operated 4 such installations and the State of Indiana 13.

It is necessary where communications are exchanged for each state police station to monitor not only the transmission of the other state police stations within the same state but also those of adjacent states and of municipal police stations in the vicinity in order that in an emergency there may be a facility available for the most rapid distribution of crime information. As an illustration in certain police stations nine radio channels are continuously observed.

Figure 9 illustrates the importance of a state radio system in a communication network. This figure shows the extensive police communication system that has been built up in and around the state of Ohio. Columbus, the control station of the Ohio State Highway Patrol, is the focal point and radio circuits extend from there in all directions.

This figure shows all the various systems of police communication that are in use for intercommunication, including teletype, radiotelephone, and radiotelegraph. Long-distance telephone and wire telegraph are used in emergencies and as extensions of this system. Since ultra-high-frequency stations do not enter this network such installations are omitted as are receiving points not equipped with transmitters. These latter points are very numerous as sheriffs' offices and the majority of cities monitor the transmissions of the state system. There are additional city-to-city circuits in existence within this territory which are not shown since they do not clear messages through Columbus.

The use of radio to set up blockades so as to isolate an area in which a serious crime has occurred is a valuable point in a statewide radio system. The co operative system in use by Michigan, Ohio, and Indiana is a splendid example; these 3 states have a planned system laid out on maps with which the dispatchers are familiar. Each police car, police post, sheriff, and municipal organization has a part to play in setting up a blockade and knows its duties in advance. Main highways and strategic points such as bridges, etc., are closed immediately, the border between states is sealed by cars and then the hunt in the territory begins. In the case above mentioned the 3 states act in unison whenever a crime is committed near the border, the cars of one state watching certain points while those of the other states watch others. Police organizations of

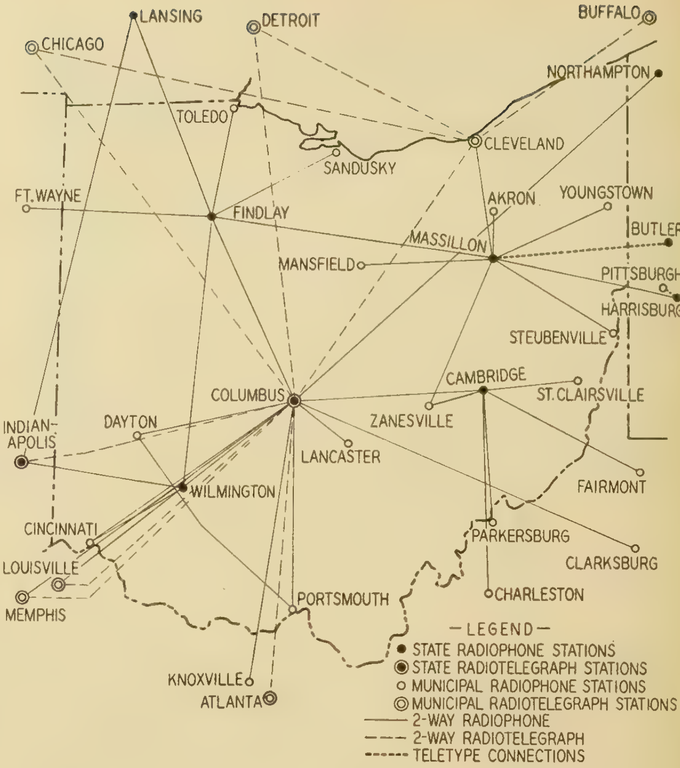


Fig. 9. Police communication channels in and around the state of Ohio

these states, numerous counties, and a score of cities participated in a recent successful man hunt and blockade.

As a general rule the state police radio system acts as a clearing house for information regarding automobile-license data and stolen- or wanted-car records. The cities having police transmitters depend upon the state police system to collect and maintain these records as well as to provide access to auto records of the state licensing authority.

In addition, it is generally considered the duty of the state police system to keep a crossfile on criminals working in the state and to advise individual departments of criminals' activities elsewhere.

Summarizing it may be stated that the police departments are using radio for 6 purposes:

1. By municipalities for one-way communication to mobile units and remote police stations

2. By municipalities for 2-way communication with mobile units

3. By states in the general dispatching of state police units

4. By states and municipalities for the radiotelegraphic exchange of police information

5. By harbor police in connection with the dispatching of harbor police boats and general policing of shipping

6. By states for emergency radiotelegraphic use in the event of interruption of the wire teletype network

All of these systems have their peculiar problems and uses. Therefore, no police radio installation should be made until adequate study has been given to the problem, in order that the equipment purchased and installed may suit the situation.

A New Approach to the Industrial Lighting Problem
Specific Lighting for Different Services

By H. B. DATES
FELLOW AIEE

Comprehensive surveys have shown the general inadequacy of artificial lighting in industry. The rapid increase of scientific knowledge on the relations of light and seeing has opened a new approach to the specification of lighting for industrial processes involving critical studies of the visual tasks, and the quality and quantity of the illumination needed. Results of the application of this new method are described in this paper.

Introduction

FOR PERHAPS thousands of years manufacturing was a home industry, pursued only in daytime, and to a considerable extent out-of-doors—the forge under a tree; the loom in front of the cottage.

Learning was the special business for the few; the mass of the human race ignorant and poor, engaged in homely, coarse occupations.

Even after the art of printing was invented and books and periodicals became cheap and abundant, artificial light was costly and scarce.

In the evolution of industry, the change from home to group production in factories, manufacturing, in the absence of any but the most primitive of light sources, was of necessity a daytime occupation but carried on indoors under a tiny fraction of the light out-of-doors. Gains in learning and the supplying of material manufactured necessities were at the heavy cost of impaired eyesight—a large capital expenditure.

Daylight

It is not generally appreciated, even today, how inadequate, in most cases, natural lighting is for indoor work requiring close, visual applications.

Daylight varies through an enormous range of brightness values. On a June day from as high as 10,000 foot-candles in the sunlight to 200 foot-candles or more just inside the window of a room. It also varies according to the time of day, the season of the year, and the state of the weather. But indoors, 25 feet back from the window, the light may be but $^{1}/_{40}$ or $^{1}/_{100}$ of that on the window sill. In interiors daylight decreases surprisingly fast as distance from the windows increases.

Consider then the conditions for seeing fine details, under natural light, in literally thousands of factories with but moderate window area, wide floors, and often with adjacent buildings shutting out the sky. It is not a question of needing artificial light only at night, but of needing it in most of the work places throughout the day.

Development of the Lighting Art

The incandescent lamp for the first time in the history of illuminants opened possibilities for a safe, convenient, and inexpensive light.

The excessive brightness of the bare bulbs, with its accompanying discomfort, and fatigue, led to the shielding of the filament from the eye by crude shades which developed into open bottom, inverted glass bowls, metal reflectors, and enclosing glass globes.

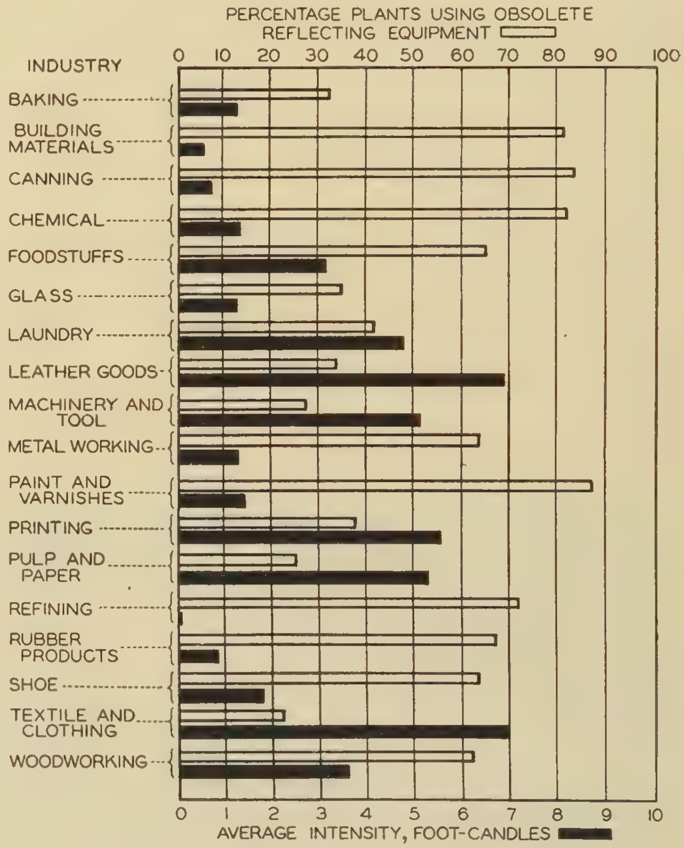


Fig. 1

Gradually as lamps improved and their use enlarged, the art of lighting developed and with it a large variety of fixtures and reflectors adapted to industrial applications.

A paper recommended for publication by the AIEE committee on production and application of light. Manuscript submitted March 8, 1937; released for publication March 18, 1937.

H. B. DATES is professor and head of the department of electrical engineering, Case School of Applied Science, Cleveland, Ohio, and chairman of the industrial and school lighting committee of the Illuminating Engineering Society.

Progress was made in lighting practice as a result of studies on the effect of better lighting on quality and quantity of output, on the prevention of accidents, and the efficiency of workers. However, lighting remained largely an *empirical art* rather than a practice resting on a scientific basis. Lighting specifications were formulated mainly from experience and opinions and tended to emphasize foot-candles, size, and spacing of lighting units, rather than lighting for the best seeing conditions for the visual tasks involved.

Seeing

The physiology and pathology of the eye have been studied intensively by the medical profession over a long period of years. The correction of refractive errors of the eye has long been on a scientific basis, but only in relatively recent years has serious attention been given to the problems of seeing and the relation of seeing and illumination.

The act of seeing involves many factors; the recognition of outline; of size; of form and detail; the perception of light and shade; quickness of seeing as involved in the observation of rapidly moving objects; the brightness contrast of the object viewed with that of its immediate background and more distant surroundings; color and glare. In addition psychological reactions must not be overlooked.

The influence of illumination on each of these factors must be studied separately; the fundamental laws determined, and methods of measurement and of evaluation developed.

This science of the relations between light and sight has made large strides and while admittedly still incomplete, knowledge has so greatly increased during the last decade that many of the physical, physiological, and psychological factors comprising the complex process called seeing can be appraised and measured; thus there is building up a truly scientific background for the lighting art.

As has been the case in every important scientific advance, so in this field there is a reluctance to abandon old empirical methods. However, the last few years have witnessed a tremendous public awakening to the importance of eyesight and a rapidly growing recognition that the primary objective of light and lighting is to promote the most accurate, comfortable, and easiest seeing and that the production and control of light are but means to this end.

Prevailing Industrial Lighting Conditions

Of the need for comprehensive studies in industrial lighting there is no question. During the years 1933 and 1934 extensive surveys were conducted throughout the United States to determine the lighting conditions in various industries as well as the average conditions in industry as a whole. In figure 1 and table I are summarized some of the findings of the surveys.

The Federal Census of 1930 listed 220,670 industrial plants in the United States.

It will be noted that as of October first, 1934, 54 per cent of the lighting equipment used in industry was of obsolete types. The average age of the lighting equipment, 8.74 years, and the average level of illumination in the work areas, 2.85 foot-candles.

However, it must not be inferred that all industrial lighting is inadequate. Much good lighting is in use providing excellent seeing conditions, though as yet it represents far too small a percentage.

The surveys further pointed out that there is a lack of proper standards for the satisfactory solution of specific lighting problems; that comparatively few industrial lighting problems have been solved to the mutual satisfaction of illuminating engineers and industrial executives, and indicated the need of fundamental studies to determine the illumination values adequate for all types of industrial processes and the best methods for supplying these values. These

Fig. 2

studies definitely show that good lighting saves eyesight, minimizes accident hazards, reacts favorably on the morale of the workers, decreases spoilage and waste of materials, and is generally effective in improving the quality of finished products.

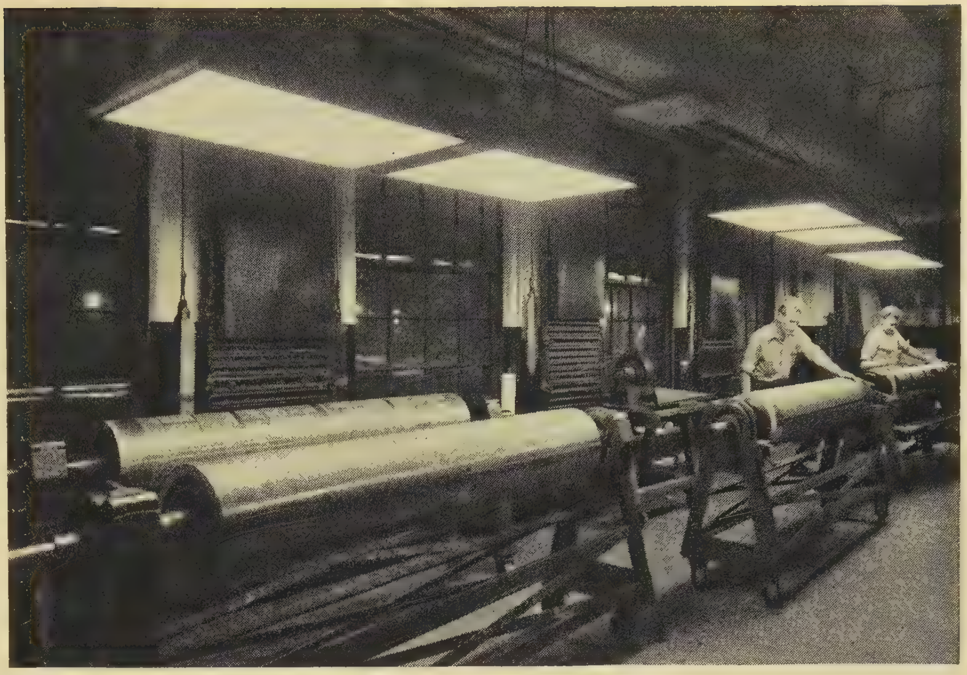


Fig. 3

New Approach to Industrial Lighting

Thirty years ago industrial plants if provided with any artificial illumination had a drop lamp over each machine or workplace. Sometimes reflectors were used, often lamps were bare and glaring. In those days if general illumination was used at all, there were a few high-powered arc lamps or clusters of carbon incandescent lamps under flat reflectors.

This was followed by a more or less universal adoption of general illumination methods where medium and large size tungsten filament lamps in scientifically designed reflectors were symmetrically spaced throughout the working area and various levels of more or less uniform general illumination were supplied. Many times these levels were of a decidedly low order and on some occasions reasonably satisfactory for most types of work.

What then is this new approach to industrial lighting? It is to study for each manufacturing process in an industry the visual task; to appraise this task in terms of the fundamental factors of seeing: size, contrast, glare, etc.; to determine the quality of the lighting and the quantity of light needed to perform this visual task accurately and quickly with comfort and ease, and without abuse to the eyes or the frequent results of eye strain noticed as headaches, irritability, and general fatigue; thus is developed as a result—a lighting specification for the process in question, and there then remains the determination of light sources and equipment to produce the specified results.

Researches in Industrial Lighting

To these ends the industrial and school lighting committee of the Illuminating Engineering Society, 2 years ago, initiated a series of comprehensive studies to determine adequate lighting solutions for industrial seeing tasks. It is the hope that as a result there may eventually be formulated, on as scientific a basis as present knowledge permits, lighting specifications for all of the important industrial operations.

To date studies have been made on:

1. Lighting in the printing industry

Table I

Classification of Manufacture	Federal Census—Number of Plants of This Type	Average Age of Present Lighting Equipment in Years	Average Foot-Candle Intensity	Per Cent Increase in Light Necessary for Good Illumination	Per Cent of Plants Using Obsolete Reflecting Equipment
Baking	15,684	7.5	1.24	195.0	32.1
Building materials	14,792	8.1	0.5	1500.0	82.0
Canning	2,917	11.7	0.6	1150.0	83.4
Chemical manufacturing	8,871	9.3	1.3	208.0	81.7
Foodstuffs, candy, dairy	46,113	8.9	3.1	271.0	65.2
Glass	8,478	5.6	1.2	460.0	35.0
Laundry	21,926	5.5	4.75	139.0	41.3
Leather goods	4,796	6.5	6.88	62.5	33.7
Machinery and tool manufacturing	11,807	6.57	5.1	106.5	27.3
Metal working	12,021	9.57	1.3	562.3	63.7
Paints and varnishes	923	17.1	1.4	494.0	87.3
Printing	22,725	5.4	5.5	109.8	37.6
Pulp and paper manufacturing	3,783	10.0	5.29	193.0	25.0
Refining	2,906	6.8	0.02	592.5	72.0
Rubber products	498	7.2	0.8	496.0	67.3
Shoe manufacturing	1,460	4.3	1.8	263.0	63.4
Textiles and clothing	24,443	5.3	7.0	115.2	21.3
Woodworking	16,527	4.0	3.6	367.0	62.4
Totals and averages	220,670	8.74	2.85	404.7	54.0

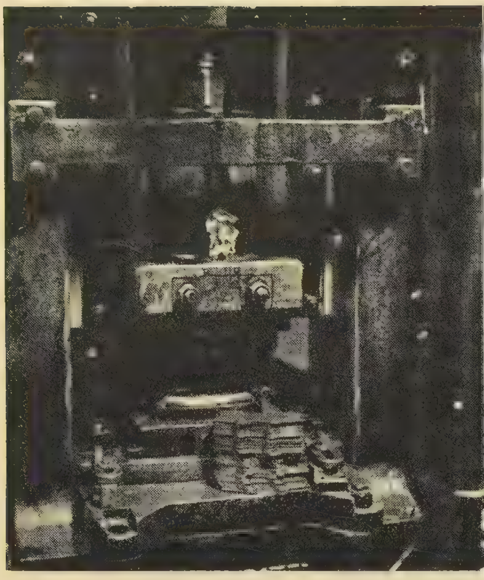


Fig. 4

Fig. 5

2. Lighting in the shoe manufacturing industry
3. Lighting in the textile industry (grey goods and denim)
4. Lighting in the candy manufacturing industry
5. Lighting for radio assembly and inspection and small parts manufacturing

According to the complexity of the industry, these studies represent from 8 months to 2 years critical and painstaking study by very competent groups of engineers. It is not claimed that they are completely exhaustive for any one industry, but as more are completed, investigations of the processes in one industry begin to overlap into other industries and progress becomes more rapid —the coverage more complete.

The projects which have been completed have been exceedingly valuable to that particular industry. In each of the completed studies it has been found that by providing proper quality of lighting and quantity of light, the ease and speed of production have been enhanced. The better morale of the workers and their lack of eye fatigue have been manifested in the amount of work accomplished. The value of this method of approach is further evidenced by the rapidly growing application of these methods by competent, progressive lighting engineers, to the large number of industrial and other lighting problems which they are called upon to solve in their daily work.

In providing good quality lighting at adequate levels of illumination, it has often been necessary, for economic reasons, to supplement general lighting by localized installations. The status of the art at the present time indicates that where more than about 50 foot-candles are needed, it is often more practical and economical to secure and control the higher level of illumination needed for good vision, by the use of supplementary lighting for the relatively small work areas involved. However, where such supplementary lighting is used, seeing conditions are impaired rather than improved if the brightness of the area being illuminated by the supplementary units exceeds too greatly the brightness of the surroundings. The absolute permissible brightness ratio is still a subject of investigation, but current practice tends not to exceed a ratio of 10 to 1.

In making recommendations for lighting specific processes, instances occasionally arise where existing equipment is not adequate or adaptable to meet the lighting requirements. Equipment designed for a particularly difficult task often is found highly suitable for other applications not previously realized.

It is obviously impractical here, due to space limitations, to quote in detail from the Illuminating Engineering subcommittee reports. It is the author's principal desire to give the AIEE members a general picture of how the specialist or the illuminating engineer now tends to approach the problem. Lighting is a specialized branch of electrical engineering and much valuable data on the subject is to be found in the *Transactions* of the Illuminating Engineering Society. It is recommended, therefore, that the electrical engineer who is not a specialist in lighting refer to these *Transactions* when he wishes specific and detailed information on particular subjects. In the references are given some of the most recent and vital presentations along specific lines.

Fig. 6

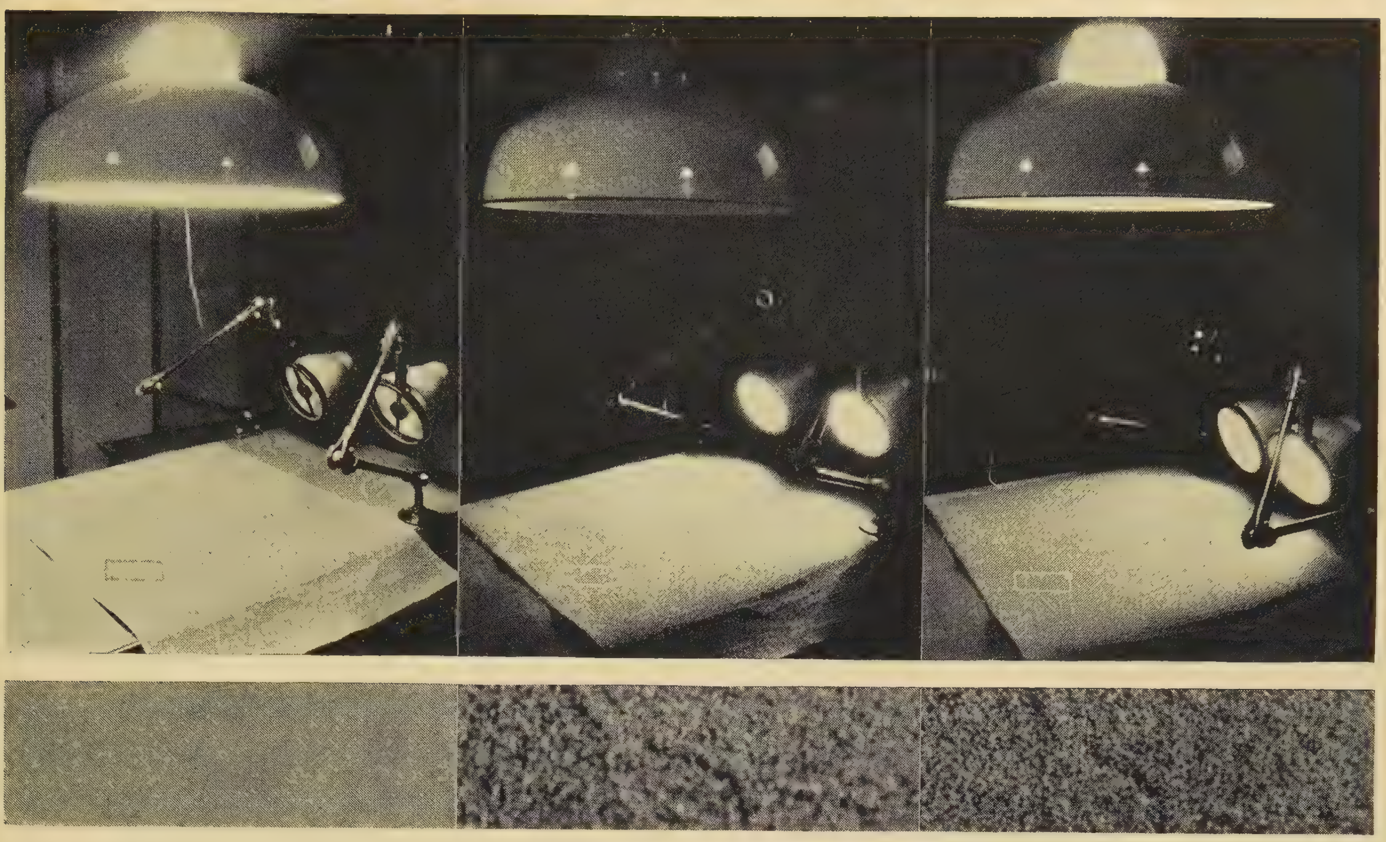


Fig. 7A. Diffused quality of light, even though of 100 foot-candles intensity, does not show defects but washes out detail

Diffused lighting, 100 foot-candles

Fig. 7B. Directional light from an oblique angle and from one direction plainly reveals the wrinkle defects

Oblique lighting, 13–15 foot-candles

Fig. 7C. Combination general and oblique lighting. With considerable diffused lighting to approximate general daylight conditions in factory, defects still show up plainly under sufficient oblique component

Diffused—30 foot-candles
Oblique—15 foot-candles

An appreciation of the value of this new approach may be enhanced by a few examples of its application to the solution of fairly difficult visual tasks.

In the printing industry critical studies of seeing type indicated that the ideal lighting should be from a large area, low brightness light source, giving a highly diffused light with an illumination of the order of 50 foot-candles. Figure 2 shows an application of this quality of lighting to the lighting of type cases, proof press, and page form, composing stones in a large newspaper plant, while figure 3 illustrates how a large light source of low brightness is effective in reducing the reflections from the surfaces of highly polished cylinders upon which are etched the various illustrations and type matter which will appear in a printed rotogravure page.

In the cotton textile industry, the weaving of grey goods presents difficult seeing tasks due to lack of contrast between the thread and the warp and finished cloth. The operator must locate and repair broken ends and see the finished cloth exceptionally well so as to locate defects and determine if all the factors contributing to the production of first-class cloth are functioning properly. Shadows on the work area are particularly annoying. The position of the lighting unit, and the quality of the emitted light have a tremendous effect on the clarity with which details are revealed.

Good general lighting is not always sufficient in itself to provide adequate seeing conditions where most needed and supplementary lighting must be supplied. Figures 4 and 5 illustrated the improvement in punch-press lighting by the addition of local lighting to the general lighting.

Inspection processes frequently present difficult lighting problems. For example: It was necessary to detect small defects such as scratches and buffed-through places on small chromium plated parts. To detect the defects rapidly it was found necessary to have the light highly diffused, with a minimum of glare and an illumination of the order of 50 to 60 foot-candles. The problem was further complicated by the large areas involved. The solution adopted is shown in figure 6.

A manufacturer of abrasives had a very difficult inspection problem, inability to detect defects in the finished product causing expense in rectifying mistakes and a considerable loss of business. In spite of rigid inspection of all the grades of sandpaper passing over inspection tables at a slow rate of speed, and being constantly watched by expert observers, the defects were slipping by, and not showing up until the eventual customer had installed this abrasive sheet upon his automatic machinery. Then an uneven abrasion appeared on the veneer or other

surfaces and caused no end of trouble in attempting to turn out a uniform product. This always produced a retroactive effect on the abrasive manufacturer by causing an expense in adjustment as well as a loss of good will. Many times, it meant an abrupt termination of a contract. Under the general conditions of factory lighting with a good daylight component, these defects were unable to be detected.

The problem consisted of seeing the small wrinkles in the abrasive sheet, which cannot be seen under ordinary general lighting. The wrinkles occur during the process of putting the abrasive on the cloth or paper background. Since the abrasive consists of small jagged particles, which have specular surfaces, general lighting, with its components of light from every direction, causes a multitude of reflections toward the eye, so that the net effect is to see a mass of abrasive surface without seeing any minute detail. Since the light penetrates into the slight hollows as well as on to the high spots, the reflections are uniform from the depressions as well as from the rest of the surface, so that the depressions or wrinkles cannot be distinguished. However, with very oblique lighting, with the rays of light just grazing the surface, the light impinges upon the higher surface, but completely misses the depressed wrinkles. This causes a shadow in the depressions, so that the wrinkles can readily be seen.

The 3 photographs (figures 7*A*, *B*, and *C*) illustrate 3 steps showing the procedure in solution of the lighting problem.

Figure 7*A* shows that even with a high intensity diffused quality of light, the defects did not show up, but on the contrary were obliterated.

Figure 7*B* demonstrates the fact that directional light from an oblique angle, and from one direction, plainly revealed the wrinkle defects.

Figure 7*C* illustrates the typical conditions under which the abrasive sheet will be seen under the proper lighting. It shows a combination of general lighting of a diffused nature, of about 25 foot-candles and an oblique component of light, of approximately 15 foot-candles. There is sufficient quantity of oblique light to still plainly show the defects, despite the tendency of the general lighting to fade them out.

If progress in industrial lighting has, in the past, been relatively slow, it may be attributed in part to a lack of proper standards for the satisfactory solution of lighting problems, and in part to the lack of appreciation of the value of good lighting not merely from the standpoint of production, but of its effect on human efficiency, human welfare, and eyesight conservation.

Much real progress is being made and the next few years will undoubtedly witness greater progress in industrial lighting than has resulted during the last 20 years.

References

Specific Industrial Lighting Recommendations

1. Lighting in the Printing Industry (committee report), Illuminating Engineering Society *Transactions*, volume 31, 1936, page 277.

2. Lighting in the Textile Industry—Grey Goods and Denim (committee report), Illuminating Engineering Society *Transactions*, volume 32, 1937, page 247.

3. Lighting in the Shoe Manufacturing Industry (committee report), Illuminating Engineering Society *Transactions*, volume 32, 1937, page 289.

4. A Practical Approach to Inspection Lighting Problems, R. G. Slauer. Illuminating Engineering Society *Transactions*, volume 31, 1936, page 369.

5. Factory Lighting To Fit the Facts, A. A. Brainerd. Illuminating Engineering Society *Transactions*, volume 31, 1935, page 315.

6. Special Lighting Applications for Industrial Lighting, J. M. Ketch, W. Sturrock, and K. Staley. Illuminating Engineering Society *Transactions*, volume 28, 1933, page 57.

Fundamental Researches on Light and Vision

7. Some Experiments on the Speed of Vision, P. W. Cobb. Illuminating Engineering Society *Transactions*, volume 19, 1924, page 150.

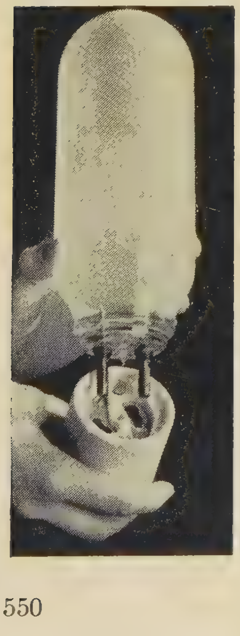
8. The Four Variables of the Visual Threshold, P. W. Cobb and Frank K. Moss. *Journal* of the Franklin Institute, volume 205, 1928, page 831.

9. The New Science of Seeing, M. Luckeish and Frank K. Moss. Illuminating Engineering Society *Transactions*, volume 25, 1930, page 15.

10. The New Science of Lighting, M. Luckeish and Frank K. Moss. Illuminating Engineering Society *Transactions*, volume 29, 1934, page 641.

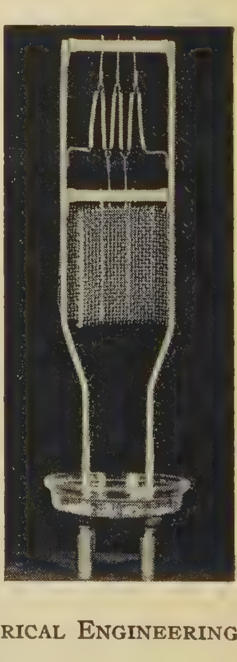
11. Analysis of the Literature Concerning the Dependency of Visual Functions Upon Illumination Intensity, L. T. Troland. Illuminating Engineering Society *Transactions*, volume 26, 1931, page 107.

12. Glare—Its Manifestations and the Status of Knowledge Thereof, P. S. Millar and S. McK. Gray. *Proceedings* of the International Commission on Illumination, 1928, page 239



New 1,000-Watt Bipost-Base Lamp

A rugged 1,000-watt general service lamp, equipped with a medium bipost base and an inside-frosted tubular bulb, recently was developed. The bulb is made of special heat-resisting hard glass which resists shock; and because of an extremely low coefficient of thermal expansion, such temperature changes as result from rain, snow, and sleet have been found in tests to cause no breakage. The bipost base offers the advantages of more accurate focusing of the filament, a simplified socket, and more dependable electrical contact; production also is simplified. The comparatively small size of the lamp makes possible the design of luminaires of relatively high efficiency and small size. Two screens or grids mounted above the filament within the lamp collect much of the normal blackening which in usual lamps is deposited on the bulb; the lamp shown in the illustrations, of course, is designed to be burned base up. The simplified production is said to result in reasonable cost.



Expulsion Protective Gaps

By W. J. RUDGE, JR. ASSOCIATE AIEE

E. J. WADE ASSOCIATE AIEE

EXPERIENCE with the expulsion protective gap since 1932, when the first commercial installation was made, has demonstrated the efficacy of this device as a means of improving service by preventing lightning outages on overhead transmission lines.

The expulsion protective gap (figure 1) consists of a weather-resisting "textolite"-wrapped fiber tube, whose ends are fitted with metal electrodes. The lower electrode has an opening through which the gases generated by the power arc are expelled. The breakdown voltage through the tube is less than that of the insulator which is in parallel, hence the lightning discharge is kept within the tube. This prevents damage to the insulator, either from the lightning or the power arc, which would result if the tube were not present. The lightning arc through the tube establishes a path for the power current which flows until the next normal current zero, at which time the expulsion action in the tube prevents further flow of current. The tube is isolated from the line by a series air gap which prevents full line-to-ground voltage being applied under continuous operation.

Expulsion gaps are particularly applicable on grounded-neutral circuits. Their ability to prevent lightning flashovers of insulators and the resulting outages and possible damage to the insulators is not dependent upon tower-footing resistance. They are equally applicable on low- and high-voltage lines. To date they have been applied on circuits ranging from 13.8 kv to 138 kv (figure 2). Experience is being obtained with installations on a 230-kv line.

Several of the major applications have been made on 138-kv systems which already had overhead ground wires and insulation consisting of 10 disk insulators. In these cases, the lines passed through areas where it was difficult to obtain the low tower-footing resistances, which are essential for proper operation of the ground wire, without considerable expense. Expulsion gaps were placed on each tower as a means of preventing insulator flashovers and subsequent experience has proved the application to operate as expected. They have also been applied to circuits varying from 13.8 kv upward, both on lines with and without overhead ground wires. Economic considerations show that in many cases they can be applied to each insulator string at a lower cost than that of lowering the tower-footing resistances by addition of counterpoises, ground rods, etc.

Expulsion protective gaps have been found particularly valuable as a means of protecting pole-top switches and river crossings. Often pole-top switches have a lower line-to-line and line-to-ground flashover than the adjacent structures on the line, making them a susceptible point to lightning flashovers. Also, pole-top switches are often used as emergency ties operated normally in an open position, which means that they are located at a reflection point and therefore subjected to higher voltages. River crossings frequently have taller structures and longer spans than normal, which means greater

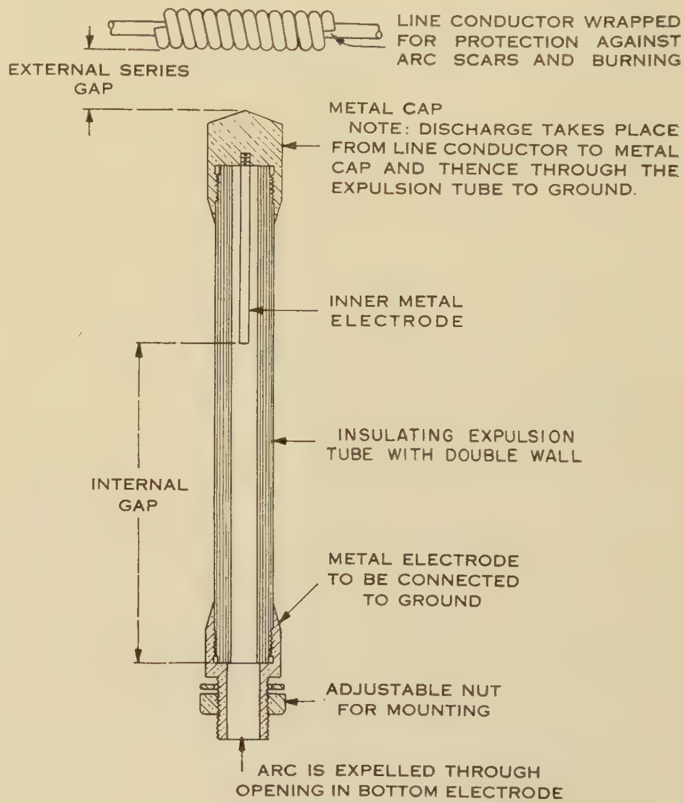


Fig. 1. Construction of expulsion protective gap

exposure to lightning. On several river crossings the use of expulsion gaps has not only eliminated circuit outages but has prevented damage to the insulators as well.

Where it is found necessary or desirable to obtain the best available lightning protection in important stations, expulsion gaps used at the line end of the shielded zone (approximately 2,500 feet long) adjacent to the station, serve to limit the magnitude of the surge voltage which can be transmitted over the conductors to the station lightning arresters. In some cases it is difficult to install an effective shielded zone for the distance of 2,500 feet from the station. Expulsion gaps installed on all structures out

A paper recommended for publication by the AIEE committee on protective devices. Manuscript submitted March 20, 1937; released for publication March 26, 1937.

W. J. RUDGE, JR., is an electrical engineer and E. J. WADE is a research engineer in the lightning arrester department of the General Electric Company, Pittsfield, Mass.

1. For all numbered references see list at end of paper.

from the station for a distance of approximately one-half mile will provide parallel paths to ground for the lightning currents and will reduce the severity of the stroke currents which must be handled by the station arresters. By using this means of discharging a part of the direct stroke currents to ground the voltage wave will be chopped and its length greatly reduced, so that protection will be secured for strokes which might otherwise result in damage to the station equipment. The gain which can be obtained in either of the above cases is greatest for lines with unusually high line insulation, such as wood pole lines having large spacings, and no guy wires.

Expulsion gaps give the best lightning protection when installed on every structure. However, in several instances it has been found that a material reduction in outages can be realized by equipping only the guyed poles. In other cases it has been found economical to equip a particular section of line or a feeder where lightning troubles have occurred frequently. When they are not installed on all structures, it is essential that the expulsion gaps have low-resistance grounds, to gain maximum effectiveness in reducing stress on the adjacent unprotected structures.

Volt-Time Flashover Characteristics

Expulsion protective gaps have a somewhat flatter volt-time flashover characteristic than plain rod gaps or disk insulators. The volt-time characteristic of a 115-kv expulsion gap is compared with that of a rod gap in figure 3. It may be noted that the expulsion gap is equivalent to a rod gap having a 34-inch spacing on the full $1^1/_2 \times 40$ positive wave. However, when tested on a wave rising to flashover at the rate of 1,000 kv per microsecond, the expulsion gap is equivalent to a 22-inch rod gap. A similar situation exists with regard to disk insulators. When tested in parallel with a string of 6 disk insulators, the expulsion gap was found to give protection on the full $1^1/_2 \times 40$ positive wave. However, when tested on a wave rising at the rate of 1,000 kv per

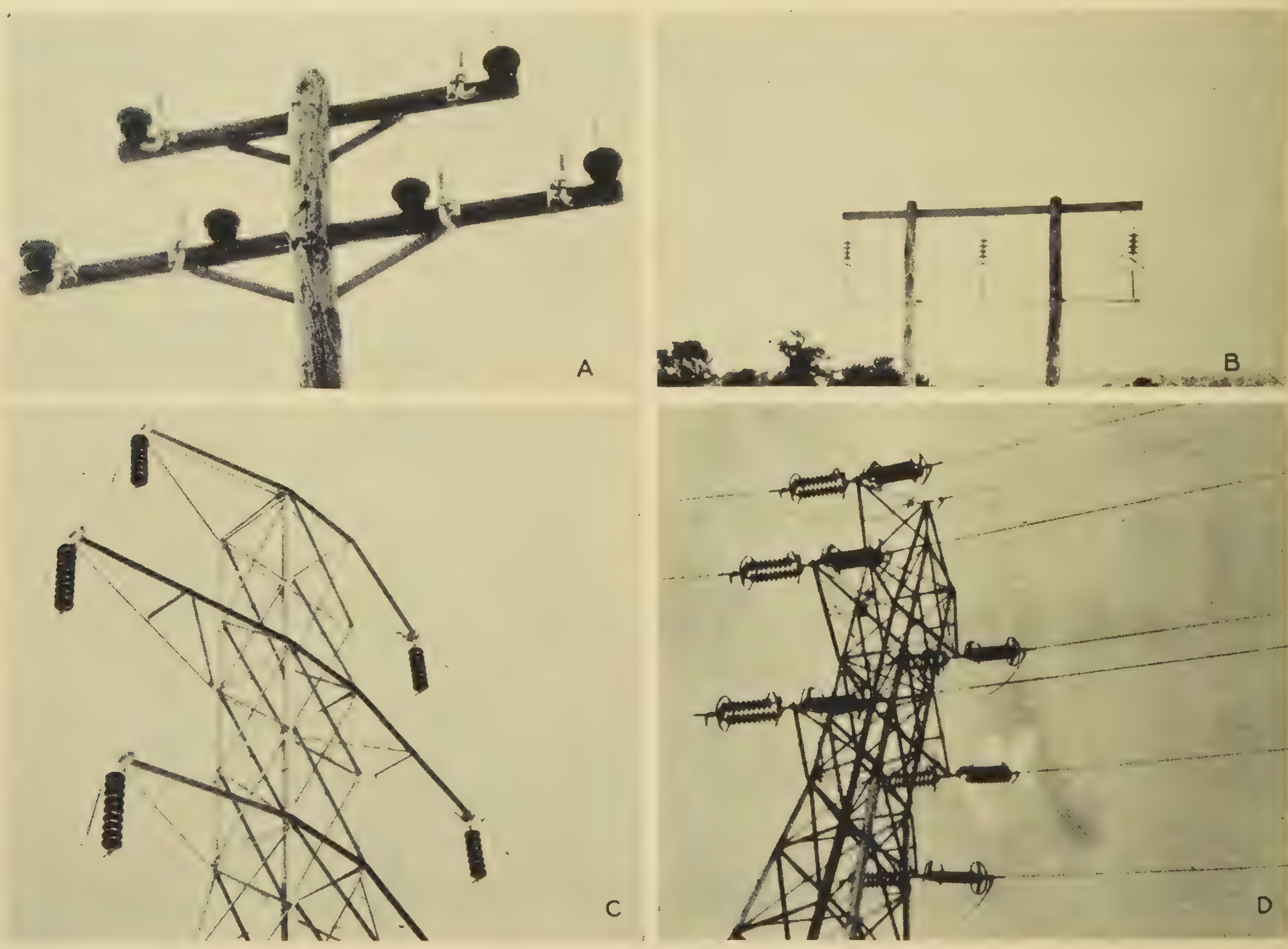


Fig. 2. Typical installation of expulsion protective gaps

A—13.8-kv system *B, C*—69-kv system *D*—138-kv system, gap on one phase during tests

microsecond, the expulsion gap protects 5 disk insulators Tests which have been made on various combinations of expulsion gaps and disk, pin, and pedestal insulators, indicate that where protection is obtained on the $1^1/_2$ x 40 full positive wave, protection will also be obtained for negative waves and waves rising in shorter times. Wave polarity has little effect on the flashover voltage of the expulsion protective gap.

The expulsion gap does not have a sufficiently flat volt-time characteristic to make it suitable for protecting transformer insulation. Comparative tests between the flashover characteristics and the breakdown strength of insulation pads such as used in transformers, show that the flash over of the expulsion gap rises more rapidly than the breakdown voltage of insulation pads, as the time to flashover becomes less.

When installing expulsion gaps, it is necessary to allow reasonable tolerances in the settings of the series air gap. Obviously, increasing the series gap raises the flashover voltage. Figure 4 shows how the protection level of a 115-kv expulsion gap is increased as the series gap is raised from 11 inches (the standard setting) to 15 inches. To estimate the increase in flashover voltage, read from a rod-gap curve, the spacing corresponding to the expulsion-gap voltage ($1^1/_2$ x 40 positive wave). Add to this spacing the number of inches by which the series gap is to be increased. From the rod-gap curve read the voltage corresponding to the larger rod-gap spacing. This will be a close approximation for the protection level of the expulsion gap with increased series gap spacing.

Impulse Discharge Characteristics

In view of the increased amount of data on direct stroke currents, it is of interest to speculate as to the probability of an expulsion gap tube being burst by direct stroke currents. Laboratory tests have shown that currents in excess of 100,000 amperes are required to burst the tubes. Lewis and Foust have shown that only one per cent of the 358 strokes measured have tower currents exceeding 100,000 amperes. A similar investigation in Germany, in which 224 strokes were reported, showed a maximum tower current of 70,000 amperes. It appears, therefore, from these data that the probability of an expulsion gap being burst from lightning is very small. Furthermore, field experience with many thousand expulsion gaps over the past 4 years has yielded only $^1/_{40}$ of one per cent where the evidence indicated that the lightning current was great enough to cause bursting.

Operating Characteristics of Expulsion Protective Gaps

In addition to providing a discharge path for lightning to earth, the expulsion gaps must be capable of interrupting the power current which flows after the lightning discharge. The maximum power current which they will safely interrupt depends upon the pressure generated in the fiber tube by the arc current. An extensive series of tests has established the relation governing the pressure generated as a function of the particular design, the physical dimensions of the fiber tube and the crest current. This makes possible the determination of the tube dimensions for any particular current (figure 5).

Since the test data is of necessity taken and correlated against crest current, it becomes necessary to convert the current values to corresponding symmetrical root-mean-square values when applying expulsion gaps to a given system. When making the conversion from crest current to the equivalent symmetrical root-mean-square value, it is necessary to apply a factor which takes into account the transient d-c component and the wave form occurring in the first half cycle of current flow. If the resistance of the circuit is zero, and the current

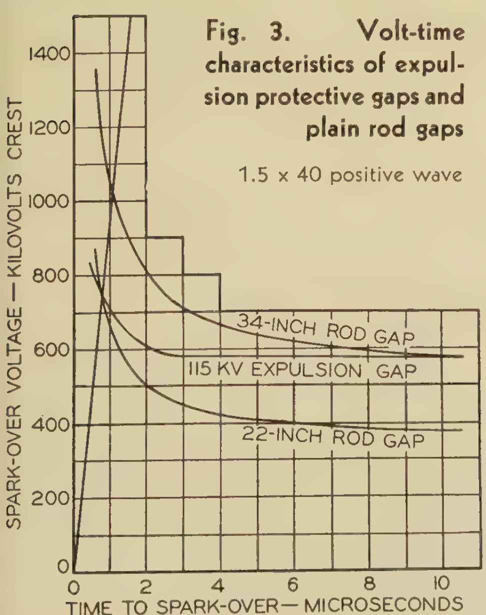


Fig. 3. Volt-time characteristics of expulsion protective gaps and plain rod gaps

1.5 x 40 positive wave

Fig. 5 (right). Maximum currents for expulsion protective gaps

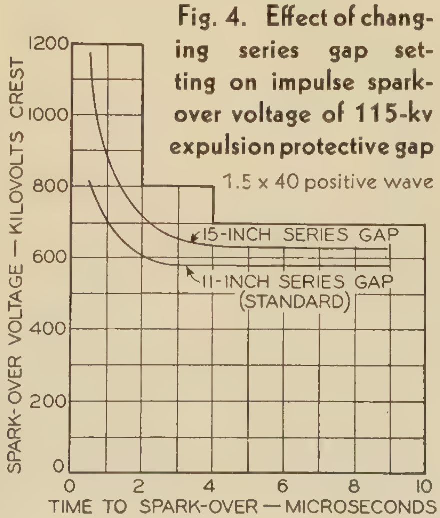
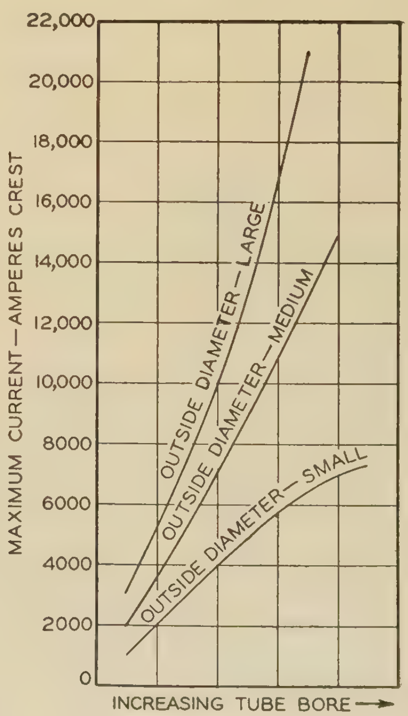


Fig. 4. Effect of changing series gap setting on impulse spark-over voltage of 115-kv expulsion protective gap

1.5 x 40 positive wave



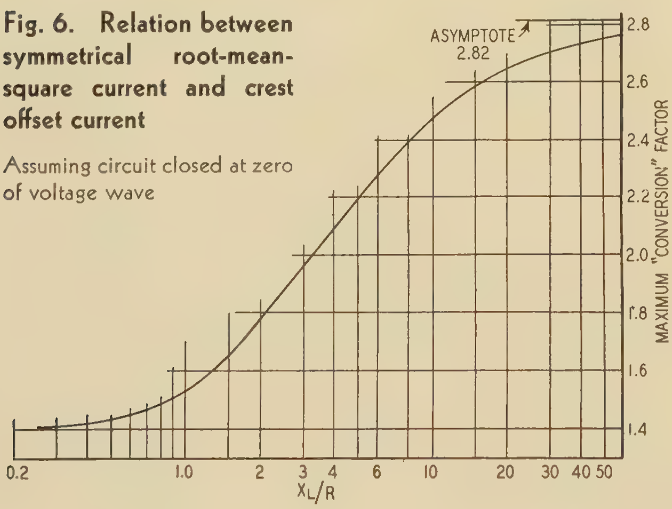
flow starts at the zero of the voltage wave, this conversion factor has a value of 2.82. However, the resistance always has a finite value and if the lightning occurs exactly at the zero of the voltage wave, follow current will not be started. Therefore, this maximum conversion factor will never be obtained. The available data from systems on which short-circuit tests have been conducted indicates that the maximum conversion factor in service does not exceed 2.4 which corresponds to a ratio x/R of 8.2 (figure 6). The ratio of x/R is the relation between the inductive reactance (i.e., the transient reactance or that reactance which is effective during the first cycle of current flow) and the resistance of the circuit. The curve shown in figure 6 gives the maximum conversion factor in a single phase circuit where the current is assumed to start at the voltage zero.

It should be noted that measurements of short-circuit currents having a duration of $^1/_2$ cycle, using bushing-type current transformers whose ratings are satisfactory for metering and relaying are likely to be in error due to core saturation as the result of residual magnetism and overloading. Staged tests made where a special current transformer was used in series with a standard bushing current transformer showed differences greater than 400 per cent. This does not mean that differences of this order will exist in all cases, but it does indicate the necessity of eliminating this source of error when determining the current which is the basis for selecting the expulsion gap.

It is always advantageous to select the expulsion gap whose rated maximum current is only slightly above the

Fig. 6. Relation between symmetrical root-mean-square current and crest offset current

Assuming circuit closed at zero of voltage wave



maximum available system current, as by so doing the minimum or required clearing current can be kept to its lowest values, thereby extending the range of system conditions for which the expulsion gap is applicable. The advantages are twofold. First, the expulsion gap selected can be used in locations where the available short circuit current is lower, i.e., on structures having higher tower footing resistance, or systems with greater neutral resistance. Second, the expulsion gaps will be capable of a greater number of operations before erosion of the fiber raises the minimum or required clearing current beyond the point of successful operation.

In a given circuit there are 3 factors which determine whether or not a particular expulsion gap will extinguish the arc in one cycle:

1. The current
2. The crest value of the (recovery) voltage which appears immediately following the power current zero
3. The rate of rise of the recovery voltage

Figure 7 shows the relation between the recovery voltage which an expulsion gap can withstand and the current during the preceding half cycle. It is apparent from these relations that the minimum current or the current required to clear depends upon the circuit characteristics. The application problem, therefore, becomes one of determining the short-circuit current and the recovery voltage of the particular circuit being considered.

Circuit Characteristics

A number of papers dealing with the recovery voltage characteristics of circuits have been presented before the Institute.[1–6] However, most of these papers have dealt with this problem in connection with oil circuit breakers, in which very high rates of recovery voltage were encountered. In the case of expulsion gaps, the recovery rates obtained in service are much lower than those for breakers. This is true because the capacitance of the line or line to earth is always in parallel with the gap. In the case of simple 3-phase circuits a fair determination of the recovery voltage can be made by calculation, however, with an extensive interconnected network, the calculation of recovery voltage becomes very complicated. Much less effort and time are required to determine the recovery voltages by test. Furthermore greater confidence can be placed in the test results, as they do not involve any assumptions. Extensive tests on a number of systems form a background of knowledge for applying expulsion gaps. Therefore tests are not necessary in every case to insure a successful application.

Field Tests

To facilitate the determination of recovery voltages on power systems, and to obtain other fundamental data on operating systems, a truck has been equipped with the apparatus suitable for field testing.

The truck is equipped with the following:

1. An automatic 3-element cathode-ray oscillograph shown at left on figure 8 which may be used to measure current or voltage on three phases of a system. The oscillograph utilizes a rotating drum type film holder, the speed of which can be varied, and a thyratron-controlled circuit which may be adjusted for different exposures. Records can be obtained from a high film speed corresponding to 25 microseconds per millimeter down to speeds which can be successfully recorded by the magnetic oscillograph.

The oscillograms are obtained by photographing the phenomena on the fluorescent screen of the cathode-ray tube using f 2.0 lenses

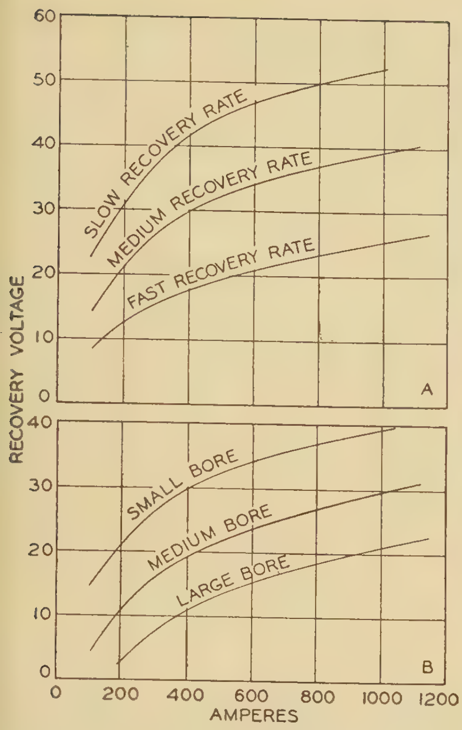


Fig. 7. Effect of bore and recovery rate on clearing current

A—Varying recovery rate—bore constant
B—Varying bore—recovery rate constant

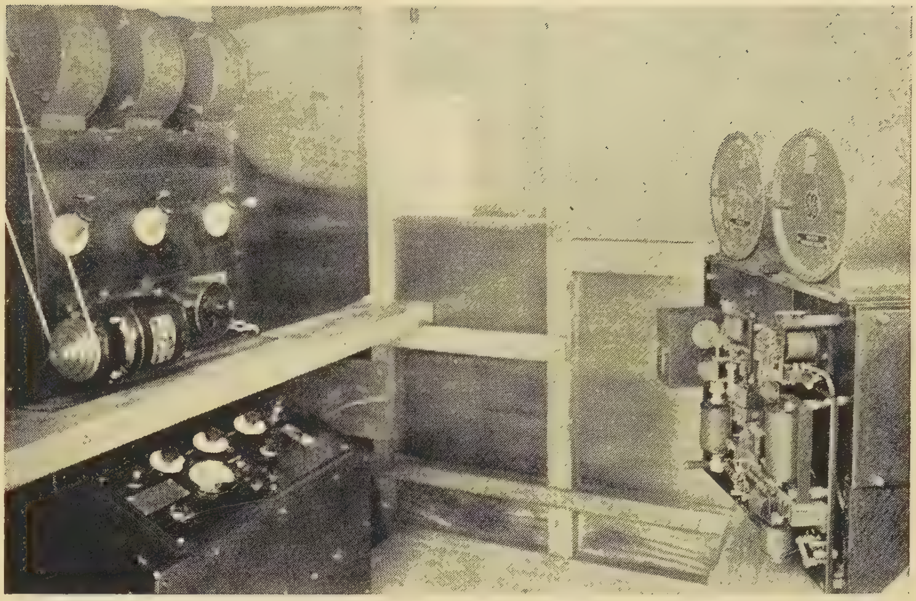


Fig. 8. Interior of truck for making field tests. View showing 3-element cathode-ray oscillograph and 6-element magnetic oscillograph

and 35-millimeter "cine" film. The magazine film drums hold 100 feet of film, and means are provided for cutting off the exposed portions after each test.

Porcelain-housed coupling capacitors are used as voltage dividers for the cathode ray oscillograph.

2. An automatic 6-element oscillograph is used for current and pressure measurements. This oscillograph is equipped with a mirror to provide the initial sweep motion, and a motor which brings the recording paper up to speed before the mirror reaches the end of its travel.

3. A pressure recorder is used for measuring the pressures developed in the expulsion protective gap and recoil forces developed during its operation. The pressure record is automatically recorded by the 6-element oscillograph during the test.

4. A ground resistance meter.

5. A dark room which enables film to be developed and examined in less than 5 minutes after the measurement.

6. A portable 110-volt power supply for operating the equipment where no such supply is available.

The equipment described above is so versatile that the effect of all circuit conditions on recovery voltage can be determined.

Figure 9 shows both the cathode-ray oscillograph and magnetic oscillograms obtained during a staged 3-phase test on a 26.4-kv system utilizing a 75-ohm neutral ground. It may be noted that the expulsion gap on phase 3 opened the circuit ahead of phases 1 and 2. The expulsion gaps on phases 1 and 2 opened simultaneously on phase-to-phase current as this current was much greater than the ground current. Had the system neutral been solidly grounded, the two last to clear would have operated on ground current at their respective current zeros.

Mountings

Proper mounting arrangements are vital to successful operation of expulsion gaps. The series gap must be controlled to prevent its becoming either too great or too small. Where the series gap becomes too small, a greater percentage of line voltage is applied continuously to the tubing, which results in corona tracking and damage to the fiber. The limits for the series gap setting are determined by 2 factors:

1. The minimum setting allowable is that which prevents excessive continuous voltage being applied to the tube, or an unnecessary number of operations.

2. The maximum setting is that beyond which protection will not be obtained for the insulators in parallel.

It is preferable to have the series gap setting as large as possible and still protect the insulation as it reduces the normal operating voltage on the fiber tube and is in the direction to keep the number of gap operations at a minimum. The ionized gases must be properly directed, to avoid flashovers due to their conductivity. Figure 10 shows the length of the flame path as a function of the power current through the flashover protector. Obviously the circuit voltage and the expulsion gap dimensions should enter in such a relation. However, the curve can be used to estimate the safe distance for objects in the direction of the flame having a different potential from that of the discharge gases. Sufficient clearance should be provided between the expulsion gap and the structure to which it is attached to assure that lightning flashovers will be confined within the expulsion gap.

Recoil forces must be considered when designing the mounting hardware. The magnitude of the recoil force is a function of the velocity and pressure of the discharge

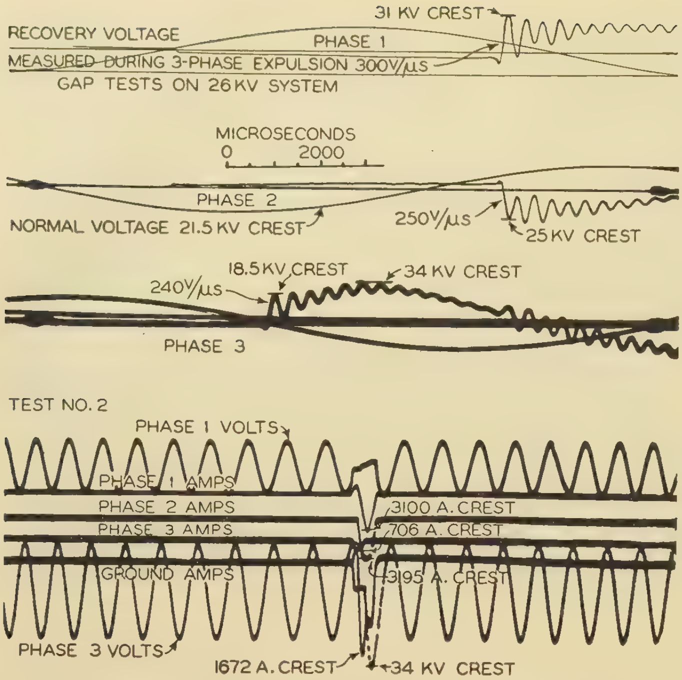


Fig. 9. Oscillograms taken on the 3-element cathode-ray oscillograph and automatic magnetic oscillograph during staged tests on expulsion protective gap for a 26.4-kv system

gases and the shape of the opening at the end of the expulsion gap. Tests have been made on flexible mountings which show that the recoil force is a function of the current and the design. The relation between these factors has been determined by an extensive series of tests and is taken into account in the finished designs. The pressure-time relation of the recoil force is of nearly the same shape as the current, although slightly lagging. While the recoil force may reach values in the order of 3,000 pounds, the time is so short that the expulsion gap and its mounting hardware does not move appreciably until the pressure has ceased. The acceleration imparted to the expulsion gap during this short period results in further movement and an oscillation whose frequency is determined by the mass of the expulsion-gap assembly and the rigidity of its mounting. The greater the mass of the assembly, the less the energy imparted by the discharge. The greater the rigidity of the mounting, the greater the stress in the mounting.

It is of utmost importance that the mounting hardware be designed to facilitate ease of installation. This results in a direct saving to the operator and broadens the field of application.

Weathering

It is felt that insufficient time has elapsed to form any definite opinion as to the ultimate life expectancy of expulsion gaps. Past experience with plain fiber tubes for expulsion gaps as well as in other applications has indicated the real necessity of providing a weather resistant covering to avoid deterioration of the fiber and warpage.

While experience to date has shown the textolite-covered tubes to have excellent weathering characteristics, and to be free from warpage, organic materials cannot be expected to have a life comparable with inorganic materials such as porcelain. Periodic refinishing of the tubes with a weather-resistant paint, will increase the weather resistance, although examination of expulsion gaps from both service and accelerated life tests, have indicated that the textolite wrapping retains its dielectric and mechanical properties when subject to the weather under normal conditions, and that refinishing of tubes is not essential. There is a slight discoloration of the outer layer of the laminated paper after the original finish disappears. However, a careful checkup has shown this condition to have had no harmful effect on either the operating characteristics or life. The electrodes and all metal parts are of selected weather resisting alloys.

Operating Experience With Expulsion Gaps

Operating experience where records have been obtained on expulsion protective gaps installed since 1933 is given in table I. It may be noted that they have been equally successful in overcoming the lightning outages for both low- and high- voltage systems. Care should be exercised, however, when interpreting the data regarding operations. The discharge indicator consists of a strip of soft copper bent across the open end of the tube. The escaping gases cause the strip to be moved from its position. Obviously this indicator does not count the actual number of operations. Usually the line is patrolled at intervals of from 1 to 2 weeks or only after lightning storms. Therefore a blown indicator can only be taken to mean that an operation has occurred since the last inspection of the line. Whether there has been one or more operations such as might occur with multiple lightning strokes will not be disclosed. It should be noted that every blown indicator does not necessarily mean a separate stroke to the line, as a severe lightning stroke may not only cause operation of all expulsion gaps on the structure nearest the point struck, but may cause operations on the adjacent structures as well. At present there is not sufficient data available to arrive at a factor which will permit determination of the number of strokes to the line in terms of indicator operations; however, it is expected that the number of strokes to the line will be somewhat less neglecting multiple strokes.

Fig. 10. Maximum flame lengths for expulsion protective gaps

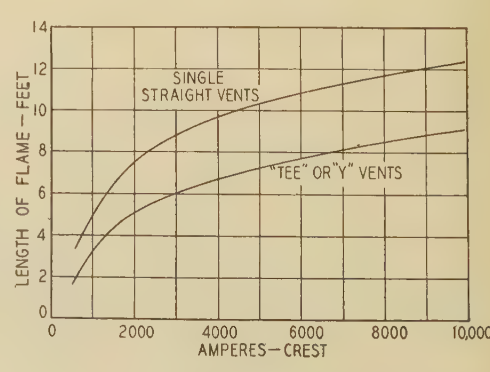


Table I—Expulsion Protective Gap Operation

Year	Line	Notes	Company	Length Line	No. Gaps	No. Structures	Structure With Gaps	Tube Operation	Tube Flashover or Failed	Tripouts
13.8-Kv Lines										
1935	13,862 13,863	2–4	Consolidated Gas Electric Light & Power Company	0.62	240 Ph. 40 Gr.	120	40	25 Ph. 2 Gr.	1†	
1936	13,862 13,863	2–4	Consolidated Gas Electric Light & Power Company	0.62	240 Ph. 40 Gr.	120	40	13 Ph. 6 Gr.		0
1935	87 88	3–4	Consolidated Gas Electric Light & Power Company	3.38	213 Ph. 71 Gr.	142	71	33 Ph. 6 Gr.	1†	0
1936	87 88	3–4	Consolidated Gas Electric Light & Power Company	3.38	213 Ph. 71 Gr.	142	71	66 Ph. 9 Gr.	0	0
1936	60 61	1–4	Consolidated Gas Electric Light & Power Company	3.46	240 Ph. 40 Gr.	160	40	37 Ph. 5 Gr.	1†	
69-Kv Lines										
1935	Holtwood** Engleside		Pennsylvania Water & Power	15.6	648	108	108	78	4†	16*
1936	Holtwood** Engleside		Pennsylvania Water & Power	15.6	648	108	108	83	0	5
1934	Safe Harbor Donegal		Pennsylvania Power & Light Company	13.4	390	130	130	28	0	0
1935	Safe Harbor Donegal		Pennsylvania Power & Light Company	13.4	390	130	130	140	0	0
1936	Safe Harbor Donegal		Pennsylvania Power & Light Company	13.4	390	130	130	166	0	0
1935	Donegal Harrisburg		Pennsylvania Power & Light Company	17.5	550	175	175	65	0	0
1936	Donegal Harrisburg		Pennsylvania Power & Light Company	17.5	550	175	175	138	0	0
110-Kv Lines										
1934	Laurinburg to Lumberton		Carolina Power & Light Company (Steel tower)‡	25.5	648	216	216	150	1	1
1935	Laurinburg to Lumberton		Carolina Power & Light Company (Steel tower)‡	25.5	648	216	216	37	0	5§
1936	Laurinburg to Lumberton		Carolina Power & Light Company (Steel tower)‡	25.5	648	216	216	19#	2	5§
1934	Lumberton to Abbotsburg		Carolina Power & Light Company (Wood H-frame)‡	18.7	491	167	167	23	0	0
1935	Lumberton to Abbotsburg		Carolina Power & Light Company (Wood H-frame)‡	18.7	491	167	167	7	0	0
1934	Abbotsburg to Wilmington		Tidewater Power Company (H-frame)‡	48.6	1230	410	410	12	2	0
1935	Abbotsburg to Wilmington		Tidewater Power Company (H-frame)‡	48.6	1230	410	410	17	1	4§
1936	Abbotsburg to Wilmington		Tidewater Power Company (H-frame)‡	48.6	1230	410	410	16	1	1
132-Kv Lines										
1933	Glenlyn Roanoke		Appalachian Electric Power Company	65	816	292	292	16		
1934	Glenlyn Roanoke		Appalachian Electric Power Company	65	816	292	292	87	12†	9
1934	Roanoke-Fieldale		Appalachian Electric Power Company	68	921	301	301	156	3†	2

1. Gaps on every fourth structure.
2. Gaps on every third structure.
3. Gaps on every second structure.
4. Gaps on each circuit of structures equipped (double circuit lines). Multiplex connection neutral tube common to both circuits.

† The cause for these flashovers has been determined and remedied.
* Twelve operations due to improper relay settings.
** Double-circuit steel-tower line.
‡ These records are incomplete.
# Operations for only one patrol of line.
§ Part of tripouts due to towers being knocked down and other causes than lightning.

Field experience has indicated to date that the average number of times an expulsion gap will be called upon to operate will not cause sufficient erosion of the fiber tube to constitute a factor in its life. From table I the number of operations per year has been worked out for the 3 circuit voltages for which records are available: 13.8, 69, and 138 kv, for which the years elapsing between operations of a given expulsion gap are, respectively, 6.7, 5.12, and 9.75.

While the present data indicate that operations occur on the lower voltage circuits more frequently than on the higher voltage circuits, further experience may show otherwise. In general this appears logical as the flashover voltage is lower and less stroke current is required to cause operation.

The operating records which have been obtained over the past 5 years with many thousand expulsion protective gaps are in themselves proof that line tripouts and outages caused by lightning can be practically eliminated. Thus, expulsion gaps increase the reliability of the system, improve the system stability, and reduce maintenance by preventing damage to the line insulators.

References

1. The Expulsion Protective Gap, K. B. McEachron, I. W. Gross, and H. L. Melvin. Electrical Engineering, June 1933, page 414.

2. The Deion Flashover Protector and Its Application to Transmission Lines, A. M. Opsahl and J. J. Torok. Electrical Engineering, June 1933, page 415.

3. Effect Which Different Distributions of Expulsion Gaps Have on Direct Stroke Protection of Transmission Lines, L. V. Bewley. *General Electric Review*, November 1935, page 505.

4. The Determination of Circuit Recovery Rates, E. W. Boehne. Electrical Engineering, March 1935, page 530.

5. Lightning Investigation on Transmission Lines—IV, W. W. Lewis and C. M. Foust. Electrical Engineering, January 1937, page 101.

6. Circuit Breaker Recovery Voltages, Magnitudes and Rates of Rise, R. H. Park and W. F. Skeats. AIEE Transactions, volume 50, 1931, page 204.

7. The Lightning Stroke: Mechanism of Discharge, K. B. McEachron and W. A. McMorris. *General Electric Review*, October 1936, page 487.

Empirical Method of Calculating Corona Loss From High-Voltage Transmission Lines

By JOSEPH S. CARROLL
ASSOCIATE AIEE

MABEL MACFERRAN ROCKWELL
MEMBER AIEE

Synopsis

It is difficult to find a mathematical formula which will fully agree with observed data on corona loss under all conditions. Therefore, a purely empirical method of corona loss calculation has been developed, based on analysis and co-ordination of the experimental data which have been accumulated at Stanford University.

Introduction

THERE IS great need for a method whereby the corona loss which will occur on a transmission line of any given description can be predetermined with a fair degree of accuracy. It is difficult to find a mathematical formula which will fully agree with observed data under all conditions. For this reason it has been thought desirable to develop a purely empirical method of corona loss calculation, based on analysis and co-ordination of the experimental data which have been accumulated at Stanford University over a number of years. These data are useful for such a purpose because they were obtained with considerable accuracy on sections of line erected out-of-doors in 3-phase configuration on actual insulator strings, and corresponding with present-day high voltage transmission practice in regard to the size, height, and spacing of the conductors.

The method developed is based on the experimental observation that the shape of the curve of corona loss versus voltage for cables of sizes used in high voltage transmission is virtually constant, and that the effect of variation in such factors as spacing, diameter, altitude, etc., is simply to shift this fundamental curve parallel to itself along the voltage axis. Having established the characteristic curve shape, the problem reduces to developing empirical rules for determining its location under any given set of conditions.

Basic Data for Study

The results of the experimental work at Stanford University have been incorporated in a series of papers[1,2,3,4,5,6] which will be used as the basic material for the present study. The effect of incomplete removal of die grease was not at first fully appreciated, and puzzling inconsistencies resulted in some cases. Hence only certain curves of the references cited are suitable for use in the present analysis, and these with due qualification for the degree of cleanliness of the conductor surface. This matter is discussed in greater detail in appendix I.

The curves selected for use are assembled in figure 1, having been replotted to semilogarithmic co-ordinates from the original test points. It is readily seen that the relative positions of the curves, when considered with respect to conductor diameter, are somewhat inconsistent with one another. These apparent inconsistencies are largely due to differences in spacing, air density, and surface condition. It is the purpose of this paper to analyze the effect of these factors and properly co-ordinate the curves.

Characteristic Shape of Corona Curve

The essential similarity in shape of the corona curves is apparent from figure 1. For calculations of ordinary accuracy any one of the curves (except that for the rope-lay cable) could be selected as typical with good results. However, close analysis shows divergencies which may possibly be of significance if very fine comparisons are being drawn or if the curves are to be extrapolated very far. Apparently the loss level at which the transition to the steeper slope occurs becomes higher as the diameter is increased. Apparently, also, the curves for the smooth segmental surface are slightly steeper than those for the stranded surface. In 2 cases the curves for stranded aluminum appear to be a little steeper than those for stranded copper, but this is believed to be largely a matter of experimental conditions. The curve for weathered stranded cable drops faster in the lower region, than does that for the same cable unweathered.

The curve for the rope-lay cable has a distinctive shape which should not be regarded as typical for any other cable. The corona characteristics of the rope-lay cable are notably poor.

For the convenience of the reader a few curves are assembled in figure 2 which are believed to be reasonably typical for various cases noted. For purposes of reproduction the numerical co-ordinates of several points on each curve are listed in table I. If any fine distinctions are to be drawn or comparisons made between the merits of different types of construction, however, the curves of figure 2 should by no means be accepted as basic, but the reader should go directly to figure 1 and use his own judgment as to what typical shape or shapes to select.

Turning to figure 3, the solid line represents the shape of a composite corona-loss curve for a cable $^1/_2$ inch to 2

A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted February 2, 1937; released for publication March 25, 1937.

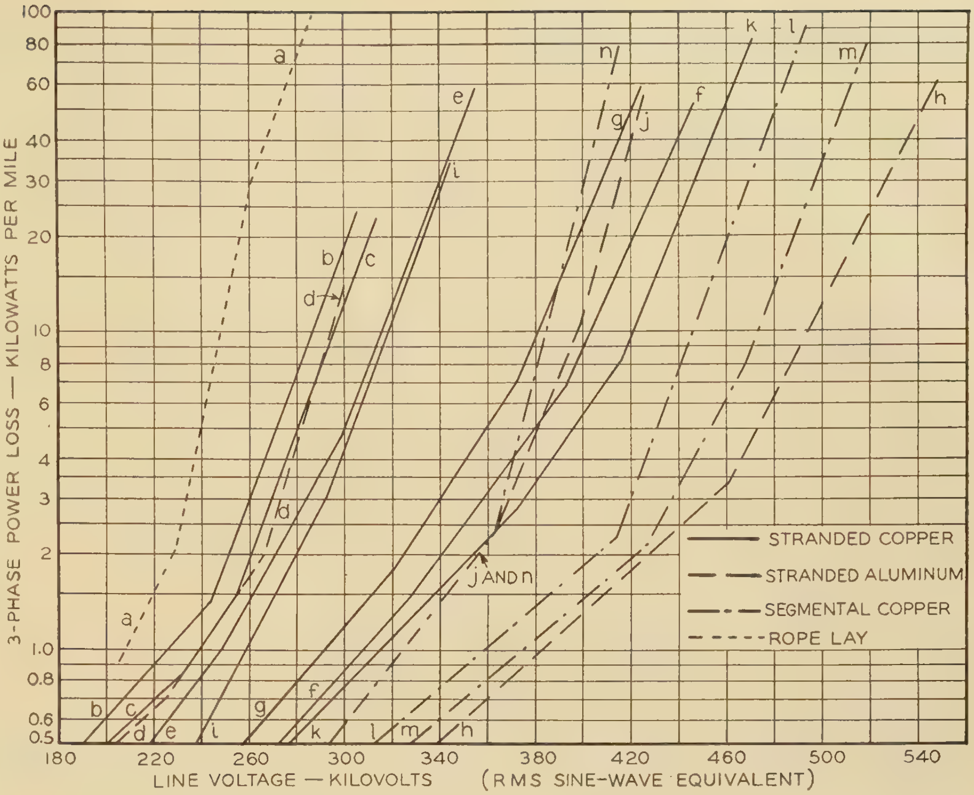
JOSEPH S. CARROLL is associate professor of electrical engineering at Stanford University, Calif. MABEL MACFERRAN ROCKWELL is a consulting electrical engineer at Los Angeles, Calif.

Fig. 1. Curves taken from references

See table I for detailed description of conductors

Curve Symbol	From Reference Number	Figure Number in Reference	Curve Number in Reference Figure
a	1	11	2
b	1	11	3
c	1	11	4
d	1	11	5*
e	3	7	2
e	3	5	5
f	3	7	4
g	3	7	5
h	3	7	7
i	3	5	4
j	4	12	3
k	4	12	4
l	4	12	6
m	4	12	8
n	5	2	1

* Caption in original paper should have read "unused."



inches in diameter, based on figure 2 but plotted in the more familiar rectangular co-ordinate form. The location with respect to the voltage scale is selected at random. If this curve is arbitrarily projected downward from a point A corresponding to about 4 kw loss, it intercepts the voltage axis at a point e_1. The shape of this curve $e_1\,AB$ then closely resembles that of the curve for a small highly polished wire ($^1/_4$ inch diameter or less), although the latter would of course be located farther to the left on the voltage axis. For the small polished wire, corona is of a fairly uniform character and begins at a definite voltage e_1 which in general is a function of the electrostatic gradient at the surface for a given impressed voltage, the nature and condition of the surface, and the air density. On the large cable, localized brushes of an unstable nature begin to occur at a relatively low voltage and cause the curve below point A to diverge from the small-wire form. However, the upper part of the curve AB, corresponding to general corona, is the controlling element and fixes the location of the entire curve. Hence it is this upper portion or its projection e_1 on the voltage axis, which should be given consideration in analyzing the relative locations of various corona curves.

Analysis of many test curves for large cables shows that if the upper part AB is projected to find e_1 the latter falls approximately at the voltage corresponding to one kw loss. This is a purely empirical observation of curve shape, but is very convenient for general use. Individual curves may deviate slightly from this general rule; but even so, the error resulting from such deviation is of second order magnitude. This is because in performing shifting operations e_1 is used merely as a basis for calculating the kilovolts shift corresponding to a certain percentage shift of the curve position. If the value of e_1 selected is, let us say, 10 per cent in error and the shift to be applied is 5 per cent, the curve after being shifted will be within one-half of one per cent of its correct position.

The curves plotted on semilogarithmic co-ordinates, figures 1 and 2, show a distinct "break" or increase of slope at about 2 to 9 kw loss. This break no doubt corresponds to the transition from the unstable brush pattern region to the region of general corona. The curves apparently follow the law $y = a^x$ fairly closely, with one or more changes in the value of a.

Shift for Air Density

Air density is given by the expression

$$\delta = \frac{17.9\,b}{459 + t}$$

where b is barometric pressure in inches of mercury, t is temperature in degrees Fahrenheit. The denominator $459 + t$ represents absolute temperature.

With lowered density the air breaks down at a reduced gradient and e_1 is decreased, shifting curves to the left. Hegy and Dunlap[6] conducted experiments at Stanford University using number 2 B and S gauge copper wire in a tank which could be evacuated to simulate various barometric pressures. The curves for different pressures were found to be parallel, furnishing a striking demonstration of the constancy of curve shape. Owing to the small size of the wires there was virtually no brush-pattern region, but the wires went almost directly into regular corona. Hence it was easy to locate their intercepts on the voltage axis. These intercepts were found to be spaced in propor-

tion to a function somewhat under the first power of the pressure. Other tests have substantiated this conclusion.

The Hegy and Dunlap results also show that when the absolute temperature of the ambient air changes, producing an inverse change in the value of δ, the intercepts follow the first power of δ. However, studies made by Nuttall[7] indicate that when the cable temperature is higher than that of the ambient air, δ should be calculated on the basis of a temperature corresponding to the ambient plus $^2/_3$ the rise above ambient.

Although the Hegy and Dunlap tests were made on small-size conductor, they actually concern not so much the conductor itself as the mobility of the ions in the air around it. Therefore, the results should apply equally well to any conductor in full corona. Hence, if the upper or general-corona portion of a curve for large-size cable be projected onto the voltage axis, its intercept e_1 should vary with air density by a law similar to that demonstrated by Hegy and Dunlap for small-size conductor.

It will be convenient to reduce all the curves of figure 1 to terms of the normal barometric pressure at sea level (29.9 inches) and 76 degrees Fahrenheit, which makes $\delta = 1.00$. Since the tests were all made close to sea level the pressure changes involved are very small, and it will be sufficiently accurate to assume that the projected intercept e_1 varies as the first power of the pressure. As the intercept also varies inversely as the absolute temperature, this means that the intercept can be taken as varying in direct proportion to δ.

In table II the air densities for each curve of figure 1 are computed, using in each case a temperature equal to the ambient plus $^2/_3$ the cable rise above ambient. These values of δ are reproduced in column 4 of table III. Column 5 of the latter table shows the kilovolts for one kw loss for each curve, which is taken as representing e_1. Then in column 6 the kilovolts for one kw loss is multiplied by $1.00/\delta$ to give a shifted position of e_1 for standard air density $\delta = 1.00$.

Shift for Spacing

Curves (*f*) and (*g*), figure 1, are both for 1.49-inch copper conductor with stranded surface. The former is at 30-foot spacing, the latter at 22-foot. The curves

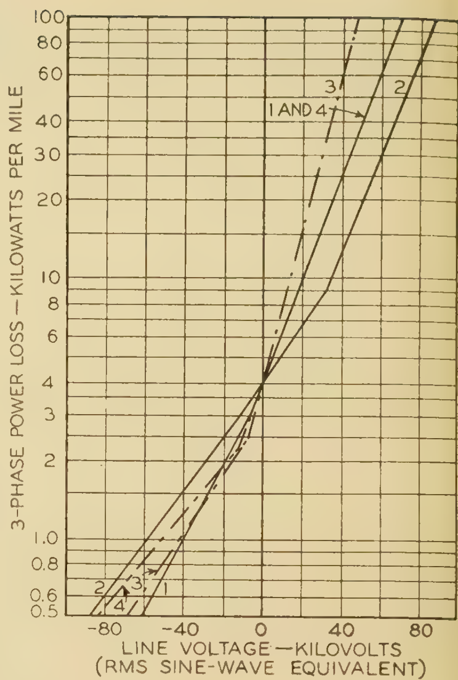


Fig. 2. Typical corona curves for weathered cable

Voltages above and below voltage for 4-kw loss

Curve 1—Concentric strand 0.9- to 1.0-inch diameter

Curve 2—Concentric strand 1.4- to 1.5-inch diameter

Curve 3—Smooth segmental 1.1-inch diameter

Curve 4—Smooth segmental 1.4-inch diameter

appear quite parallel, with possibly a slight divergence at the higher losses. Column 6 of table III shows that the kilovolts for one kw loss on the 2 curves are respectively 307 and 295, after the shift to $\delta = 1.00$ has been applied. The curve for the smaller spacing is therefore to the left of that for the larger spacing. The reason for this is that with the smaller spacing the electrostatic capacitance between the wires is greater, and hence the concentration of stress at the conductor surface is greater with the same applied voltage. Since the amount of charging current is an index of the concentration of stress, we might expect the variation in charging current to be an inverse index of the variation in e_1.

The ratio of voltages, 30-foot spacing to 22-foot spacing, at the one-kw loss level is $307/295 = 1.04$. Charging currents at the 2 spacings, calculated by the method given in Pender's Handbook,[8] show an inverse ratio of 1.052 for the center conductor, and 1.037 for either outer conductor. These values agree with the actual observed values of charging current. Apparently the outer conductor charging current is the more accurate index of the variation in e_1.

Of course, the mere fact that the e_1 ratio checks the charging current ratio for one experimental point does not prove that the charging current is necessarily a correct index of e_1 for all other variations in spacing. It is merely the best hypothesis that is available in the light of present knowledge. It should be applied with caution, especially where the range covered is very different from that represented by the change from 22-foot to 30-foot spacing. Fortunately the curves in figure 1 are all at spacings of 20, 22, or 30 feet, and so in reducing them all to terms of a common spacing—say 22 feet—no correction need be applied greater than that of 1.04 already experimentally established for the change from 22 to 30 feet. For the small change from 20 to 22 feet an interpolation, direct or logarithmic, should be sufficiently accurate, giving in either case a correction factor of 1.01.

Table I—Points for Typical Corona Curves of Figure 2

3-Phase Kilowatts Loss Per Mile	Line Voltage—Kilovolts Above or Below Kilovolts for 4-Kw Loss			
	Curve 1	Curve 2	Curve 3	Curve 4
0.5	−61	−87	−69	−84
1.0	−40	−59	−42	−51
2.0	−19	−29	−15	−19
2.2				−12 (break)
2.4			−9 (break)	
2,8		−14 (break)		
3.0	−7 (break)			
4.0	0	0	0	0
6.0	+9	+15	+6	+9
9.0		+32 (break)		
10.0	+20	+34	+13	+20
20.0	+35	+55	+24	+35
40.0	+50	+66	+34	+50
100.0	+70	+88	+48	+70

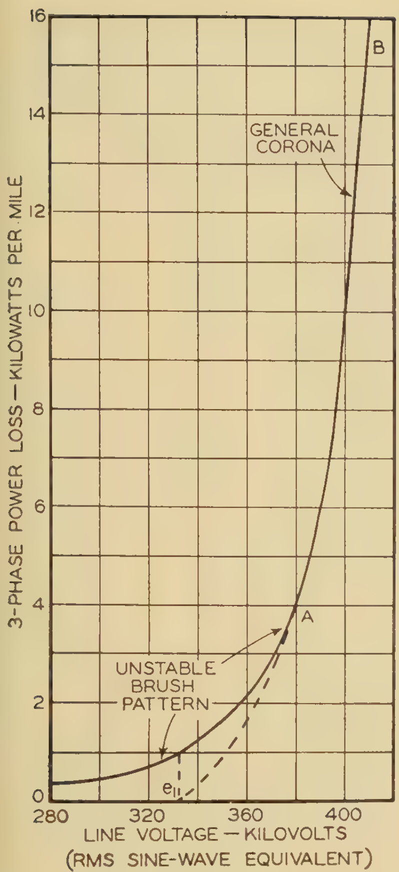


Fig. 3. Composite corona curve for cables $^1/_2$ to 2 inches diameter based on typical curves of figure 2, converted to rectangular-co-ordinate form

If the transition from one spacing to another occurs with a conductor size different from the 1.49-inch diameter applicable to curves (*f*) and (*g*), the correction factor would not be expected to be affected much, as a study of capacitance tables indicates that the ratio of charging currents for two different spacings varies only slightly with conductor diameter in the range $^1/_2$ to 2 inches.

In column 7 of table III are listed the factors for correcting each curve to terms of 22-foot spacing. Applying these factors to the kilovolts for one kw at $\delta = 1.00$ given in column 6, there are obtained the values of column 8. The latter represent the kilovolts at one kw for $\delta = 1.00$, 22-foot spacing. Comparing these figures with the corresponding points from the original curves, column 5, the difference (column 9) represents the net kilovolt shift to cover the corrections to standard air density and spacing. Since it has been established that changes in air density and spacing produce virtually parallel shifts of the curves, then the kilovolts shift at any other loss level will be the same as the kilovolts shift at the one-kw loss level. For instance, column 10 of table III gives the kilovolts for 4-kw loss on the original curves of figure 1, and column 11 gives the same figures with the kilovolt shift of column 9 added or subtracted as the case may be. Thus column 11 represents the kilovolts for 4 kw loss at 22-foot spacing, $\delta = 1.00$.

Shift for Weathering

Curves (*e*) and (*i*) of figure 1 show the effect of weathering on a new 1.125-inch copper stranded cable after it had been dragged in loose gravel on level ground. In the original record (figure 5, Carroll and Cozzens[3]) the intermediate stages are also shown. It is there seen that the dragging moved the corona curve very sharply to the left, compared to its position just after the gasoline, soap and water wash of the new cable; but that almost at once, the curve started to move back to the right due to weathering. After 4 months it had returned approximately to its original location. In fact, in figure 5 of Carroll and Cozzens (and also in figure 1 of the present paper, where the initial and final curves are reproduced), the final curve lies actually to the right of the initial curve. However, the temperature was higher, and the barometric pressure lower, at the time the final curve was taken; hence the air density was appreciably less. When the curves are both placed on an equal footing of standard air density, as is done in table III, column 8, it is found that they become virtually coincident at the one-kw point. Observation showed that after the 4-month weathering period no further appreciable change occurred.

The weathered and unweathered curves differ in shape in the lower or brush-pattern region. Hence their true relationship is shown more clearly by focussing attention on a higher level of loss—say 4 kw, where the general corona region is entered and the 2 curves become nearly parallel. At this level column 11 of table III shows that under standard air density conditions the curve (*i*) for dragged and weathered conductor lies at 291 kv and the curve (*e*) for new conductor at 296 kv. This represents a correction factor of 291/296 = 0.983 to be applied to the kilovolts for 4-kw loss of any curve taken just after a gasoline, soap and water wash of the degree of thoroughness which prevailed in the experiments for the Carroll and Cozzens paper,[3] to represent the effect of dragging and weathering as described in the same paper.

Table II—Values of Air Density for Curves of Figure 1

Figure 1 Curve Symbol	Barometric Pressure in Inches Mercury	Ambient Temperature, Degrees Fahrenheit	Cable Temperature, Degrees Fahrenheit	Rise Degrees Fahrenheit	Ambient + $^2/_3$ Rise Degrees Fahrenheit	Air Density Based on Preceding Column
a	29.90	67.5	76.5*	9*	73.5	1.006
b	29.87	64	73*	9*	70	1.011
c	29.90	68	77*	9*	74	1.006
d	29.94	80	89*	9*	86	0.985
e	29.84	77	86*	9*	83	0.987
f	30.05	71	80	9	77	1.002
g	29.85	80	82	2	81	0.990
h	30.05	66	80	14	76	1.007
i	30.17	60	68	8	66	1.030
j	29.75	93	102	9	99	0.956
k	29.92	71	80*	9*	77	1.000
l	29.91	76	88	12	84	0.986
m	29.57	82	94	12	90	0.966
n	30.16	60.5	68	7.5	65.5	1.032

* Estimated

It may be said at this point that despite the divergence in shape, the use of the kilovolts for one kw loss to represent e_1 in applying the spacing and air-density shifts to the curve for dragged and weathered cable introduced no ap-

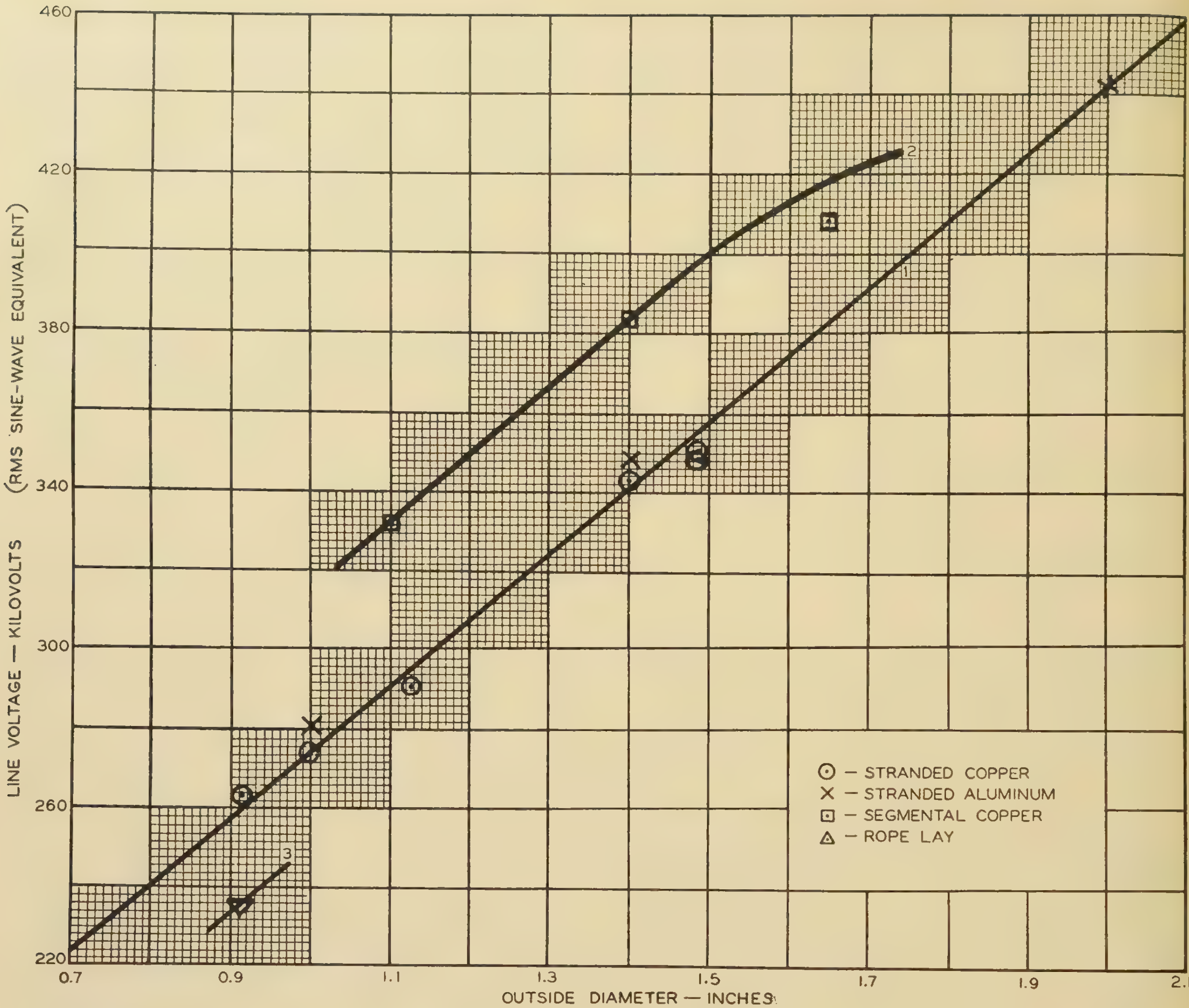


Fig. 4. Co-ordination curves

Kilovolts for 4-kw 3-phase corona loss per mile. Dragged and weathered conductor; 22-foot flat spacing; sea level; air density = 1.00; 60 cycles per second; Curve 1—Concentric strand; Curve 2—Smooth segmental; Curve 3—Rope lay

preciable error, because in that case the relation of a weathered to an unweathered curve was not under analysis. The one-kw point might have been a few kilovolts in error in representing the true e_1 of the dragged and weathered curve, but this would have a negligible effect on the amount of the shift obtained by applying the correction factors for air density and spacing.

It has been stated that the correction factor for weathering as determined from curves (*e*) and (*i*) applies only when the initial condition is similar to that just after a gasoline, soap and water wash of about the degree of thoroughness which prevailed in the experiments for the Carroll and Cozzens paper.[3] This covers only curves (*e*) to (*i*), figure 1. Curves (*j*) to (*n*) inclusive, which were taken from the Carroll, Cozzens, and Blakeslee paper[4] and the Carroll and Simmons paper,[5] represent a somewhat more thorough type of cleaning than do the curves of the earlier papers, and hence may be expected to lie relatively a little farther to the right than do the earlier curves. Hence it would not be reasonable to expect the weathering process to be able to return the cable, after dragging, to a condition having a curve as close to the initial one, as was true in the earlier cases. A weathering factor of 0.92 might be estimated for the later curves (*j*) to (*n*). Conversely, the very early curves (*a*) to (*d*), taken from figure 11 of Carroll, Brown, and Dinapoli[1] were not quite so well cleaned as the Carroll and Cozzens curves, and so would have a weathering factor of perhaps about 0.99.

It is recognized that the estimates of weathering factor, other than that for the curves of the Carroll and Cozzens paper where a definite experimental tie exists, are more or less empirical. However, they are believed to be quite

reasonable, because when the kilovolts for 4-kw loss under standard conditions given in column 11 of table III are corrected for weathering according to the factors derived above and the resulting voltages (column 13) are plotted as functions of conductor diameter, the points fall in such a way as to define a set of smooth curves (see figure 4).

Co-ordination Curves

The curves of figure 4 represent the kilovolts for 4-kw loss for a group of conductors of various diameters and structures all reduced, so far as is possible in the light of present knowledge, to terms of the same air density, conductor spacing, handling, and weathering. As such they constitute a co-ordination of existing data and furnish a convenient means of interpolation for determining losses on conductors not covered by published corona-loss curves.

The points fall naturally into 2 groups—one for the smooth segmental cable (type *C* of the Carroll, Cozzens, and Blakeslee paper[4]) and the other for stranded cable. In addition there is a lone point for rope-lay cable which falls far below the curve for concentric strand. This rope-lay cable has an extremely irregular surface, as it consists of 7 large strands twisted together, each of these large strands being composed of 7 wires, 0.101 inch in diameter. Hence it is not surprising that its corona characteristics should be notably poor.

At the other extreme of surface smoothness lies the segmental cable, the 3 points for which lie well above the curve for stranded cable and appear to define a curve of their own. The authors have ventured to apply a curve shape for this cable which misses the point for 1.65 inch diameter, because the sample of the latter which was tested was of foreign manufacture and had been handled much more than the other cables.

That the curve for smooth segmental cable actually belongs above that for stranded cable is brought out especially well by the 3 points for 1.4 inch diameter. These were all taken from the curves of the Carroll, Cozzens, and Blakeslee group and hence the cleaning conditions were similar.

The transition from rope-lay to smooth segmental cable represents a variation between the extremes of very large strand size and zero strand size. Between these extremes lie the points for the ordinary concentrically stranded cable; and as already noted, these points all fall very close to a representative straight line. This is despite the fact that the strand sizes in the individual cables vary considerably. However, it is probable that the ratio of strand size to diameter is the really significant factor, because this is a measure of the degree of irregularity of the cable. In this respect the cables classed as "stranded" varied from a ratio of 0.065 to a ratio of 0.11. Attempts to find any reliable evidence of variation in loss with strand size ratio within this range were unavailing, and it is apparent that the differences, if they exist, are so small as to be masked by slight differences in surface cleanliness, etc.

The points for stranded aluminum might possibly be thought to define a curve of slightly different location than that for stranded copper; but it is believed that this is merely a matter of slight variations in experimental conditions and that no true distinction exists. Many attempts to establish a difference between the characteristics of the copper and aluminum surfaces have led to the conclusion that there is none. (See for example, Weidlein's paper.[2])

Effect of Conductor Height

Nothing has been said as yet of the effect of conductor height above the ground. This can be neglected in most cases, because the height of the experimental lines at Stanford corresponded fairly well with general transmission-line practice. The minimum clearance to the earth was 30 feet, and the maximum 46 feet. No difference in the corona on the upper and lower parts of the catenary could be observed. A mean conductor height of 35 feet gave a

Table III—Reduction of Curves of Figure 1 to Standard Conditions

Column	1	2	3	4	5	6	7	8	9	10	11	12	13
					Kilovolts for One Kw Loss					Kilovolts for 4-Kilowatts Loss			
Curve Symbol	Outside Diameter, Inches	Conductor	Flat Spacing, (Feet)	Air Density δ	Original Curve	Times $1.00/\delta$	Correction to 22-Foot Spacing	Corrected Curve, 22-Foot Spacing $\delta = 1.00$	Net Kilovolt Shift	Original Curve	Corrected Curve, 22-Foot Spacing $\delta = 1.00$ (Column 10 + Column 9)	Further Correction for Weathering	Weathered Curve, 22-Foot Spacing $\delta = 1.00$
a	0.91	Rope Lay	20	1.006	208	207	1.01	209	+ 1	237	238	0.99	236
b	0.91	Stranded copper	20	1.011	227	224	1.01	227	0	267	267	0.99	264
c	1.0	Stranded copper	20	1.006	239	238	1.01	240	+ 1	276	277	0.99	274
d	1.0	Stranded aluminum	20	0.985	239	243	1.01	245	+ 6	278	284	0.99	281
e	1.125	Stranded copper	22	0.987	249	252	1.00	252	+ 3	293	296	0.983	291
f	1.49	Stranded copper	30	1.002	308	307	1/1.04	295	−13	370	357	0.983	351
g	1.49	Stranded copper	22	0.990	292	295	1.00	295	+ 3	352	355	0.983	349
h	2.0	Stranded aluminum	30	1.007	383	381	1/1.04	366	−17	467	450	0.983	442
i	1.125	Stranded copper*	22	1.030	259	251	1.00	251	− 8	299	291	1.00	291
j	1.4	Stranded aluminum	30	0.956	325	340	1/1.04	327	+ 2	376	378	0.92	348
k	1.4	Stranded copper	30	1.000	315	315	1/1.04	303	−12	385	373	0.92	343
l	1.4	Segmental copper	30	0.986	360	365	1/1.04	351	− 9	427	418	0.92	384
m	1.65	Segmental copper	30	0.966	376	389	1/1.04	374	− 2	447	445	0.92	409
n	1.1	Segmental copper	22	1.032	325	315	1.00	315	−10	371	361	0.92	332

* Dragged and weathered; all other curves immediately after gasoline, soap and water wash

calculated value of charging current which checked well with observed values. In these calculations the ground plane was assumed to be at the surface of the earth, which appears to be true electrostatically for the normal balanced condition even where it is not true from the standpoint of return flow of ground fault currents. Thus the element of variation of ground plane level below the earth's surface is eliminated from corona calculations, and hence different transmission lines will not vary greatly in mean conductor height. Any correction that is to be applied will be quite small, as it enters logarithmically from the inverse charging-current calculation.

Effect of Frequency

The curves of figure 1 were all made at 60 cycles. For other frequencies there will be no horizontal shift of the curves, but all ordinates should be multiplied by a correction factor. For frequencies not far different from 60 cycles this factor is given closely enough by $f/60$.

Effect of Atmospheric Conditions

Humidity will have practically no effect on the corona loss if the conductor is absolutely clean. When the cable is dirty or greasy, however, increase in humidity tends to increase the loss.

A rainstorm increases the corona loss temporarily, due to the formation of brushes from the drops of water which adhere to the surface of the conductor. The same is true of a deposit of fog droplets or dew upon the surface.

Abundance of rain may be expected to accelerate the weathering process somewhat, especially if grease removal is involved.

Summary—Determination of Corona Loss Under Any Given Conditions

To determine the corona loss to be expected from any conductor under any set of conditions, the procedure is as follows:

1. Read from figure 4 the root-mean-square kilovolts corresponding to 4-kw 3-phase loss per mile for the conductor in question. If the ratio of strand size to diameter is much above 0.11, interpolate a new curve between that for "concentric strand" and that for "rope lay."

2. Figure 4 represents the ultimate condition of a cable dragged over crushed rock in the manner described in the Carroll and Cozzens paper[3] and subsequently weathered for several months. If any departure from this condition is anticipated an appropriate correction should be applied to the kilovolts for 4-kw loss, as follows:

(*a*). It does not matter much whether the cable was originally clean or greasy, except that in the latter case it may take longer for the condition of figure 4 to be attained.

(*b*). If the cable is dragged very severely over jagged rocks which actually abrade the surface, it can never be expected to return to the condition represented by figure 4.

(*c*). If the cable is installed with no dragging at all the weathering process should gradually return it, even if it was originally greasy, nearly to the condition of a new clean cable. See (*d*). Much progress beyond this point seems unlikely.

(*d*). For a new cable thoroughly cleaned by the technique of the Carroll, Cozzens, and Blakeslee paper[4] the kilovolts for 4-kw loss will exceed the values of figure 4 by about 8 per cent (representing division by the factor 0.92).

3. Plot the kilovolts for 4-kw loss, corrected as above, on semilogarithmic co-ordinates representing loss vertically and voltage horizontally.

4. Draw through the point so plotted, a corona curve of appropriate shape. As a short cut this may be based on the "typical curves" of figure 2, though if any fine distinctions between different types of cable are to be drawn, it is recommended that the reader use his own judgment based directly on the experimental curves of figure 1. If a new clean cable is to be considered, the slope of the lower portion of the curve should be made a little less steep than is indicated by figure 2.

5. After the curve is drawn, it should be shifted at the one-kw loss point to correct for air density and conductor spacing. For the spacing shift use the following table:

22 to 30 feet—multiply kilovolts by 1.04
22 to 20 feet—divide kilovolts bo 1.01

Interpolate logarithmically. For extrapolations of any great range, correct in inverse proportion to the charging current on the outer wire. This method of extrapolation has not been completely verified, however, and should be used with caution.

For the air density shift, since the values of figure 4 are based on a density of 1.00, multiply the kilovolts for one kw by the anticipated air density, using a temperature equal to the ambient plus $^2/_3$ the cable rise. This will be sufficiently accurate where the change in barometric pressure is not very great. If a wide range is to be covered, as by going to a high altitude, the shift should probably be made more nearly in proportion to the $^2/_3$ power of the barometric pressure. Until experimental work can be carried out at high altitudes it is impossible to be completely certain of this rule, as it now rests largely on laboratory evidence.

A convenient way to perform the shift at the one-kw point is to compute the total net shift and determine the new kilovolts for one kw. Then make a movable voltage scale and slide it sidewise until this new voltage is directly under the one-kw loss point of the curve. Securing the movable scale in this location it is then possible to read off the loss at any desired voltage, as for example 230 kv. This method is especially helpful if a number of different conditions of altitude, temperature, etc., are to be investigated for a given line.

A numerical example of the loss calculation is worked out in appendix II.

Conclusions

1. Experimental evidence shows that the shape of the curve of corona loss versus voltage for cables of sizes used in high voltage transmission is virtually constant

2. The major effect of variations in diameter, spacing, altitude, temperature, surface structure, and surface condition is to shift the

characteristic curve parallel to itself along the voltage axis

3. The amount of the shift which will result from any given change in conditions can be determined empirically on the basis of experimental data. Thus the characteristic curve can be placed in a location corresponding to any given set of conditions and the loss for any voltage determined

4. By this means corona-loss calculations for large conductors are placed on a foundation of carefully co-ordinated experimental evidence.

Appendix I—Selection of Curves From References

The paper by Carroll, Brown, and Dinapoli[1] is the earliest of the references to be considered, and in this paper the importance of thorough cleaning was just beginning to be understood. Though some washing of conductors was carried on, it is now known that by later-day standards this cleaning was imperfect in many cases, leaving some die grease between the strands which kept oozing out, collecting dust, and giving erratic results. It is believed, however, that the curves of figure 11 may be accepted for comparison with later data, having been taken immediately after a fairly good gasoline, soap and water wash. Curve 1 of figure 11 is to be rejected, however, because the conductor had surface irregularities which resulted in abnormally poor corona characteristics.

The paper by Weidlein,[2] next in order of publication, contains no curves taken with conductor sizes and spacings used in high-voltage transmission lines, but is important in pointing out the effect of surface conditions and in showing that "corona losses from copper and aluminum conductors are the same after weathering."

In the next paper, that by Carroll and Cozzens,[3] the washing methods were fairly good. Curves 2, 4, 5, and 7 of figure 7, namely, those which are marked "washed," may be accepted for use in the present analysis. Those marked "new" cannot be used due to the grease present on the surfaces. Figure 5 of this reference is also very important because it shows clearly the relation between corona loss on a washed new cable and that to be expected after the cable has been dragged on crushed rock and then erected and allowed to weather for several months. Figures 4 and 6 are not particularly pertinent in the present study as they have to do with cable which has been buffed, scratch-brushed, etc.

In the paper by Carroll, Cozzens, and Blakeslee,[4] improvement was made in cleaning methods, as it had been learned that all grease must be removed from between the strands and inside the cable to avoid any traces of oozing afterward. All the earlier curves of this paper are summarized in figures 12 and 13. Figure 12 is for the cables after gasoline, soap and water wash; figure 13, after a clear water wash. The latter gets the cables a little cleaner for the moment but the results do not last any length of time at all, so that comparative measurements are most difficult. The gasoline, soap and water wash, however, leaves the conductor surface in a quite stable condition which is satisfactory for comparisons and which is modified only very gradually as weathering occurs. Furthermore, it is important to stick to the "gasoline, soap and water wash" curves to preserve the important tie-in between loss under this condition and that occurring after dragging and weathering, given by figure 5 of Carroll and Cozzens.

In figure 12 of Carroll, Cozzens, and Blakeslee, curves 5 and 9 are reproductions of curves 4 and 7, figure 7, Carroll and Cozzens. Curve 1 is to be eliminated due to incomplete grease removal and difficulty in obtaining smooth stranding with the multiple I-beam construction. Curve 2 is also eliminated because it was calculated from single-phase measurements and because the cleaning is believed to have been incomplete. Curve 7 is eliminated because it was made on a sample of cable produced before manufacturing methods had been perfected, resulting in surface irregularities. This leaves curves 3, 4, 6, and 8 of figure 12 as the only ones furnishing data pertinent to the present study.

In the Carroll and Simmons paper[5] the washing methods were of the best and curve 1 of figure 2 can well be utilized in the present study.

Appendix II—Numerical Example

Problem

Determine the corona loss to be expected on a 50-mile section of line located at 1,250 feet elevation, temperature 100 degrees Fahrenheit. The line is to be built of 0.95-inch concentric-strand cable and operated at 230 kv. The conductors will be arranged in a flat horizontal configuration with 25-foot spacing. They will be rendered reasonably free from grease at the factory.

Solution

From figure 4, curve 1, the kilovolts for 4 kw = 267.

In the absence of any information to the contrary it is a fair assumption that the dragging and weathering conditions will be similar to those applying in figure 4 (except for the first few months when residual grease may be present to increase the loss). Hence the kilovolts for 4 kw read from figure 4 can be used directly with no correction applied.

Curve 1 of figure 2 may be used as a short cut to indicate the typical curve shape. The zero of the voltage scale then represents 267 kv. The curve passes through one-kw loss at minus 40 kv, which would then represent 267 − 40 = 227 kv. This can be taken as the approximate value of e_1.

The spacing is to be changed from 22 feet in figure 4, to 25 feet in the actual case. A change from 22 feet to 30 feet, or 8/22, gives a correction factor of 1.04. The change contemplated is from 22 feet to 25 feet, or 3/22.

By logarithmic interpolation the new correction factor would be:

$$c_s = 1.00 + \left[\frac{\log (3/22)}{\log (8/22)} \times (1.04 - 1.00)\right] = 1.00 + \left[\frac{\log 3}{\log 8} \times 0.04\right] = 1.00 + \left[\frac{0.4771}{0.9031} \times 0.04\right] = 1.02$$

The barometric pressure at 1,250 feet is approximately 28.5 inches of mercury. Hence

$$\delta = \frac{17.9 \times 28.5}{459 + 100} = 0.913$$

Hence net correction factor for e_1 is 0.913 × 1.02 = 0.931

Corrected e_1 = 0.931 × 227 = 211 kv at one kw.

If curve 1 of figure 2 is considered to be so located that its one-kw loss is at the new e_1, or 211 kv, then −40 on the scale represents 211 kv. 230 kv will be 19 kv farther to the right or at (−40 + 19) = −21 kv. The loss for this point on the scale is seen to be about 1.9 kw per mile. Hence the loss for the 50-mile section of line will be 50 × 1.9 = 95 kw.

References

1. Corona Loss Measurements on a 220-Kv, 60-Cycle, 3-Phase Experimental Line, J. S. Carroll, L. H. Brown, and D. P. Dinapoli. AIEE Transactions, volume 50, 1931, page 36.

2. Corona Energy Loss—Influence of Surface Conditions as Affecting Corona Energy Loss From High-Voltage Transmission Lines, W. D. Weidlein. AIEE Transactions, volume 51, 1932, page 154.

3. Corona Loss Measurements for the Design of Transmission Lines to Operate at Voltages Between 220 Kv and 330 Kv, J. S. Carroll and Bradley Cozzens. AIEE Transactions, volume 52, 1933, page 55.

4. Corona Losses From Conductors 1.4 Inch Diameter, J. S. Carroll, Bradley Cozzens, and Theodore M. Blakeslee. AIEE Transactions, volume 53, 1934, page 1727.

5. Corona Losses at 230 Kv With One Conductor Grounded, J. S. Carroll and D. M. Simmons. AIEE Transactions, volume 54, 1935, page 846.

6. Corona Loss vs Atmospheric Conditions, L. Hegy and G. W. Dunlap. AIEE Transactions, volume 53, 1934, page 272.

7. The Influence of Conductor Temperature and Various Surface Conditions on Power Loss Due to Corona on Conductors at High Voltage, A. K. Nuttall. Thesis, Stanford University, 1932.

8. Handbook for Electrical Engineers, Pender. John Wiley and Sons, New York, 1922, pages 192, 207, 208.

9. Development of a Corona Loss Formula, Discussion by W. S. Peterson. AIEE Transactions, volume 52, 1933, page 62.

Properties of Saturants for Paper-Insulated Cables

By G. M. L. SOMMERMAN
MEMBER AIEE

Synopsis

The results of tests made on 9 viscous mineral oils of various types and on mixtures of these oils with 8 resins are presented. The physical and electrical properties, stability to oxidation, and stability to gaseous ionization are correlated with the viscosity index and chemical composition of the oils and resins. The catalytic effects of metals on oil oxidation are studied. Gaseous ionization in insulation voids is found to exert a physical pressure and to accelerate saturant oxidation.

Introduction

IT is generally agreed that the selection of saturating compounds for impregnated paper insulation is a problem of great importance and one which requires considerable investigation. This problem has been reviewed in the past by Riley and Scott[1] and others. The saturants must meet a number of requirements concerning their physical properties such as viscosity, set point, coefficient of expansion, and surface tension. These are particularly important for materials used in solid-type, paper-insulated cables (the type commonly used at 66 kv and lower voltages). Here, correct physical properties are necessary to minimize migration of the saturant and consequent void formation caused by the combined action of gravity heads and cable operating temperature cycles. In addition, the saturants must meet certain requirements concerning electrical and stability properties, the most important of which are the following:

1. A reasonably low power factor.

2. A high oxidation stability (as measured by power factor change) so that the power factors of cables may be uniform notwithstanding unavoidable chances for oxidation in manufacturing operations, and so that possible exposure of the cable insulation to oxygen will not result in greatly increased power factor.

3. A low susceptibility to contamination (as affecting the power factor) so that possible exposure of the saturant to impurities both before and after it is absorbed by the paper will not result in greatly increased power factor.

4. A high stability to gaseous ionization (resistance to wax formation and gas evolution) caused by electrical stress in voids which may form in the insulation with use so that the amount of gaseous ionization will not increase cumulatively.

It is sometimes stated that it is better to expend effort in reducing the possibilities of oxidation and contamination than to mitigate them in other ways. Higher impregnating tank vacuums, inert gas flushing, and improved technique in both manufacturing and installing cables are steps in this direction. The users of cables, however, have obtained considerable evidence that the power factors of the most carefully made cables increase with time, even when the cables are stored. It is therefore still considered advisable to choose saturants which are resistant to oxidation and contamination, provided other properties are not sacrificed.

Cable saturants usually consist of mineral oils and mixtures of these oils with resinous materials. Materials of these classes have recently been considerably improved in certain respects. In this paper are presented the results of an extended research in which both the older and more recently developed materials have been investigated to determine their suitability as saturants for solid-type, paper-insulated cables. Much of it is also applicable to impregnated paper and insulating oils in general.

The general procedure followed in this investigation was to subject various prospective materials to a series of chemical, physical, electrical, and stability tests in order to determine how well they meet the requirements. The advantages of this procedure are several: (1) a great many materials may be investigated at comparatively small expense, leaving only the most promising materials to be tried out on the larger scale of fabricating test lengths of cable and subjecting them to load cycle life-tests; (2) small scale tests are subject to closer control than large scale tests; (3) the exact points of strength or weakness of a material are indicated and not merely the fact that it is good or poor; (4) the physical, electrical, and stability properties may be correlated with fundamental chemical properties. This last information can be used to indicate directions in which to look for better materials.

Experimental Method

Measurements of power factor and dielectric constant were made on the materials at 60 cycles by means of a modified Schering bridge. The detector circuit of the bridge consisted of a 4-stage resistance-capacity coupled amplifier, 60-cycle band-pass filter, and an ordinary copper-oxide voltmeter which was not affected by mechanical vibrations. Magnetic pick-up was eliminated by connecting the amplifier directly to the detector terminals of the bridge, the entire detector circuit being shielded at guard potential. The power factor sensitivity was 0.00001 with 2,000 volts applied.

The electrical properties of the saturants were measured at 25, 45, 65, and 85 degrees centigrade at a stress of 15 volts per mil. The test cell was of nickel and glass construction, of the type described by Balsbaugh, Kenney,

A paper recommended for publication by the AIEE committee on research. Manuscript submitted February 23, 1937; released for publication March 23, 1937.

G. M. L. SOMMERMAN is a research engineer in the American Steel and Wire Company, Worcester, Mass.

The author wishes to express his appreciation to those in the company who have given advice and encouragement, and to acknowledge the assistance of Stina B. Long and D. W. Ross in the experimental work.

1. For all numbered references see list at end of paper.

and Herzenberg,[2] but of larger dimensions so that the air capacity was 89 micromicrofarads.

The electrical properties of cable paper impregnated with the saturants were also measured at 25, 45, 65, and 85 degrees centigrade. The test cell pictured in figure 1 was used, the method of preparing the samples being as follows. Several sheets of paper were placed between the disk electrodes and subjected to a mechanical pressure of 15 pounds per square inch by means of the springs in order to ensure good contact between paper and electrodes. The paper was dried at 110 degrees centigrade and 1 millimeter mercury absolute pressure for several hours and the saturant was simultaneously degassed under the same conditions. The saturant was then admitted to the cell and allowed to impregnate the paper for 2 hours. After this period the specimen was cooled to 85 degrees centigrade and an inert gas was admitted until one-half atmospheric pressure was attained. With this procedure the moisture content of the impregnated paper was less than 0.2 per cent when measured by the ASTM method *D*95-24 using xylol. Variations in moisture content below 0.2 per cent were found to have no measurable effects on the power factor of the impregnated paper. That the procedure yielded a thorough impregnation was shown by the fact that the ionization factor (increase in power factor on raising the stress from 25 to 125 volts per mil at room temperature) was less than 0.00003.

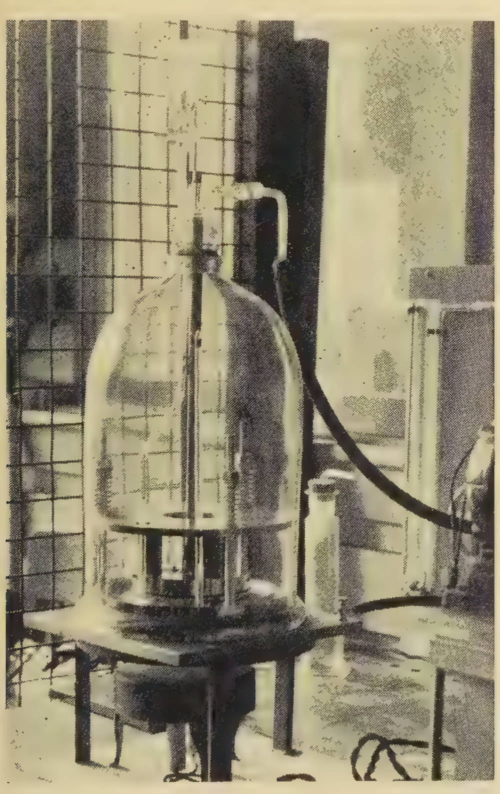


Fig. 1. Cell for testing impregnated paper

The relative oxidation stabilities of the saturants were determined by means of aging tests. Porcelain beakers containing samples of the materials were placed in an oven held at 120 degrees centigrade. The beakers were provided with loose fitting covers which kept dust out of the samples, but which did not prevent free access of air. The samples were removed at intervals for electrical measurements. This was accomplished with a minimum disturbance to the sample by immersing the measuring cell in the beaker, cooling them to 85 degrees centigrade, and placing them in a temperature-controlled box. After testing, the beaker and cell were removed from the box and heated to 120 degrees centigrade, the cell then removed, and the beaker placed in the oven for further aging. Oxidation tests made at various temperatures indicated that the rate of oxidation increased by 7 per cent per degree centigrade. The aging temperature was therefore maintained to within 0.5 degree centigrade of 120 degrees centigrade in order to minimize errors in oxidation stability results. Also, it was found that the rate of aging depended on the amount of the sample in the beaker, i.e., on the surface-to-volume ratio. A sample with a surface-to-volume ratio of 0.182 centimeter^{-1} aged 1.60 times as rapidly as one with a ratio of 0.066 centimeter^{-1}. (This may mean that the rate of removal of dissolved oxygen by combination with the oil was comparable with the rate of diffusion and convection of the oxygen through the oil, resulting in a lower concentration of dissolved oxygen in the lower portion of the sample.) By close control of aging temperature and surface-to-volume ratio (at 0.066 centimeter^{-1}), it was possible to duplicate beaker oxidation test results to within 3 or 4 per cent.

The stability of the saturants to gaseous ionization was determined by applying an electric stress of 85 volts per per mil to saturated paper sheets in the cell shown in figure 1. In the preparation of the sheets, holes were punched in some of them and connecting slits cut between the holes and the edges of one of the sheets, so that artificial voids of known size were created in the sample after drainage of the excess saturant. (This scheme is similar to that developed at the Detroit Edison laboratory.) The cell was evacuated and a certain amount of inert gas was admitted so that the voids became filled with this gas. Carbon dioxide at 20 centimeters mercury absolute pressure was used in most of the tests, as this gas is extensively employed in flushing cables prior to saturation. The gas in the voids was ionized by the electric stress, the ionization factor of the sample being 0.04. After 96 hours exposure to ionization the sheets were removed and examined for wax formation. This was facilitated by extracting the saturant from the sheets and dyeing some of them as described by Robinson.[3]

Materials Investigated

Results obtained for 9 mineral oils and 8 resins are presented in this paper. Descriptions of these materials and data concerning their chemical composition are given below.

The Oils

The oils are the most viscous cylinder stocks made for commercial use by a number of different refiners. They were selected so that the principal fields of crude supply and types of refining procedures are represented. See table I.

In order to obtain information concerning the composition of the oils, various methods of analysis were used. One method was that of viscosity index developed by Dean and Davis.[4] In this method, an extreme Pennsylvania-type (paraffin base) oil having a relatively flat viscosity-temperature curve is assigned a viscosity index of 100, while an extreme California-type (asphalt base) oil having a relatively steep viscosity-temperature curve is assigned a viscosity index of 0. The viscosity indices of the 9 oils were calculated from their respective viscosity-temperature curves, and are included in table I.

Table I—Description of Mineral Oils

Oil	Viscosity Index	Proportions of Basic Constituents: Paraffinic	Naphthenic	Residual
O-1	−1	0	70	30
O-2	4	0	65	35
O-3	65	35	30	35
O-4	84	55	35	10
O-5	90	60	30	10
O-6	96	55	35	10
O-7	96	65	30	5
O-8	100	65	30	5
O-9	104	85	10	5

O-1 to *O*-3 Gulf Coast and East Texas crudes
O-4 to *O*-9 Midcontinent and Pennsylvania crudes
O-1 to *O*-4 Acid refined
O-5 to *O*-9 Solvent, fuller's earth or aluminum chloride refined

Further information on the composition of the oils was obtained by subjecting samples to selective solvent extraction processes. With the processes used, it was possible to separate an oil into 3 classes of constituents: (1) paraffinic, (2) naphthenic, and (3) residual. (These terms, commonly used in petroleum technology, will be defined on the basis of molecular structure in the discussion.) In this way the relative proportions of the basic constituents in the oils given in table I were obtained. It is seen that the oils of high viscosity index are rich in paraffinic constituents; these oils are hereafter called paraffinic oils. The oils of low viscosity index are rich in naphthenic constituents; they are hereafter called naphthenic oils.

Table II—Description of Resins

Resin	Color	Acid Number	Saponification Number	Oxidized Resin Content
R-1	Black			Large
R-2	Red	155	164	Medium
R-3	Yellow	189	193	Small
R-4	Yellow	174	185	Small
R-5	White	186	186	None
R-6	Red	15		Medium
R-7	Yellow	12		Small
R-8	Yellow	37	93	Small

The Resins

A tabulation of the resins and their descriptive and chemical properties is given in table II. The resins *R*-1, *R*-2, *R*-3 are various grades of commercial wood rosin containing appreciable proportions of oxidized constituents (oxyabietic acids, aldehydes, ketones) and of nearly neutral oils. Resin *R*-4 was obtained by treating *R*-2 with solvents which removed most of the oxidized constituents and oils, while *R*-5 was obtained from *R*-4 by a further treatment which yielded a white crystalline form of pure abietic acid. By causing rosin to react with alcohols under special conditions, the resin esters *R*-6 and *R*-7 of low acid number were obtained. Resin *R*-8 was produced by a polymerizing reaction which also removed a large proportion of oxidized constituents.

Solubility of Resins in Oils

When a resin is mixed with heated oil, a certain amount may fail to dissolve. Part of the insoluble matter settles to the bottom of the mixing container as a sludge, while part remains suspended in the oil. Data are given in table III. Resins *R*-1, *R*-2, *R*-6, which contain large percentages of oxidized constituents (table II) are highest in insoluble matter. Oils having a high content of certain types of residual constituents, such as *O*-3, dissolve much of the oxidized resin, while oils which are low in these constituents, such as the paraffinic oil *O*-9 or the naphthenic oil *O*-2, dissolve little of the oxidized resin.

The resins *R*-3, *R*-4, *R*-5, *R*-7, *R*-8 are practically entirely soluble in all the oils. When some of these oil-resin mixtures are allowed to stand at room temperature over a period of weeks, however, a gradual crystallizing out of some of the resin occurs. This behavior has also been observed by Kirch and Riebel.[5] It indicates that a certain amount of impurities is necessary in the resins in order that they may stay in solution in the oils. In the present work it was found that the optimum purity of the resin depends on the oil used. For example, resin *R*-4 is of greater than optimum purity for use in highly paraffinic oils *O*-7, *O*-8, *O*-9, as it crystallizes out when mixed with them, but this same resin mixed with oils containing more naphthenic or residual constituents, such as *O*-1, *O*-2, *O*-3, stays in solution perfectly, even when cooled to −10 degrees centigrade. *R*-5 is of greater than optimum purity for all the oils.

When oil-resin mixtures are oxidized, many of them form a resinous sludge. This is disadvantageous mainly in cable manufacturing as the impregnating tanks and pipe lines may become coated with sludge, and also the entrainment of suspended sludge on the outer layers of the cable insulation may hinder impregnation. The laboratory aging tests indicated that the sludge formation was large in mixtures made with resins which originally contained much oxidized material. Mixtures made with the purer forms of resin sludged somewhat when the oils used were predominantly paraffinic, but did not sludge in the other oils.

Physical Properties

The principal requirements concerning the physical properties of saturants for solid-type cables are the follow-

ing. The surface tension must be fairly high to enable the saturant to be drawn into and held by the paper capillaries. The viscosity at the impregnating temperature (105 to 115 degrees centigrade) must be fairly low in order to obtain a thorough and economical impregnation. Throughout the temperature range in which cables may be installed or operated (−10 degrees to 80 degrees centigrade) the viscosity must be high to minimize saturant migration and, in case of injury to the lead sheath, bleeding of the saturant, yet the saturant must possess sufficient lubricating value to enable the cable to be bent. The coefficient of expansion should be low in order to minimize void formation caused by expansion and contraction of the saturant arising from temperature changes in service.

Data on the physical properties of the oils and oil-resin mixtures are given below.

Viscosity

The viscosities of the oils at 100 degrees Fahrenheit are from 1,800 to 6,000 Saybolt seconds, and at 210 degrees Fahrenheit are from 100 to 180 Saybolt seconds. While discussing viscosity it is valuable to introduce the term *viscosity ratio*, which may be defined as the ratio of the viscosity at 100 degrees Fahrenheit to that at 210 degrees Fahrenheit. For oils of a given viscosity at 210 degrees Fahrenheit, the *viscosity ratio* is related to the viscosity index. Thus, for an oil of 140 Saybolt seconds viscosity at 210 degrees Fahrenheit, and viscosity index χ, the *viscosity ratio* is $15 + 0.22\ (100\text{-}\chi)$.

From the viscosity requirements it follows that the viscosity-temperature curve of an ideal saturant for solid-type cables should exhibit a uniformly high value from −10 degrees centigrade to 85 degrees centigrade and then drop rapidly to a low value above 100 degrees centigrade. Unfortunately, no saturant having this characteristic has been found. The best compromise seems to be to select a saturant whose viscosity is fairly low at 110 degrees centigrade and which rises rapidly with decrease in temperature, but not so rapidly as to destroy the lubricating value at −10 degrees centigrade. Highly viscous saturants possessing *viscosity ratios* between 30 and 40 have been found very satisfactory.

Table III—Percentage of Resin Insoluble in Oil

Oil	Resin *R*-1	*R*-2	*R*-3	*R*-4	*R*-5	*R*-6	*R*-7	*R*-8
O-2		6		0	0			0
O-3		2		0	0			
O-4	10	4	0	0	0	5	0	0
O-9		7		0.3	0	8	0.3	0

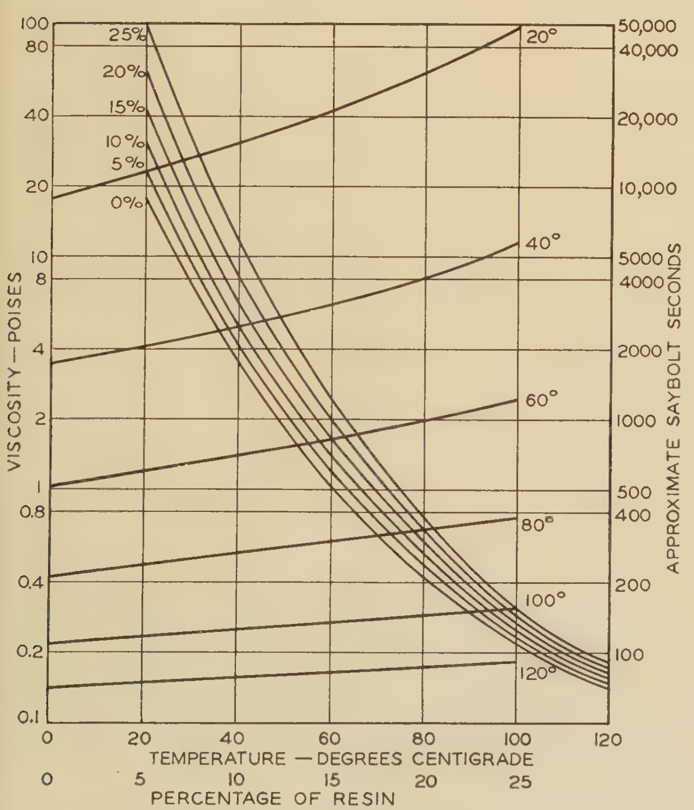


Fig. 2. Variation of viscosity with temperature and viscosity with percentage of resin for mixtures of resin and oil O–4

The addition of resin to oil changes the viscosity characteristics as shown in figure 2. The effect is greater if the polymerized resin *R*-8 is used. It is seen that the addition of resin not only raises the viscosity, but also the *viscosity ratio*. This is due to the fact that the *viscosity ratio* of the resin itself is extremely high, about 10.[8] This effect of resin additions is advantageous if the oil alone does not possess a high *viscosity ratio*, as it leads to greatly reduced migration of the compound in service, without requiring a much longer impregnation period.

Pour Point

The pour points of the oils are all below 0 degree centigrade, in some cases as low as −12 degrees centigrade. The oils do not set even at these temperatures because they are dewaxed. The addition of 15 per cent resin raises the pour point about 5 degrees centigrade. However, mixtures of resins with the most viscous oils possess sufficient lubricating value at −10 degrees centigrade for cable bending requirements.

Table IV—Specific Gravity and Coefficient of Expansion of Oils

Viscosity Index	Specific Gravity ρ (at 25 Deg C)	Coefficient of Expansion $-(1/\rho)(d\rho/dT)$ (per Degree C)
High	0.88 to 0.90	0.00070
Medium	0.90 to 0.92	0.00067
Low	0.92 to 0.94	0.00064

Specific Gravity and Coefficient of Expansion

Oils of low viscosity index have higher specific gravities and lower expansion coefficients than oils of high viscosity

index as shown in table IV. The addition of 15 per cent resin to the oils increases the specific gravities and reduces the expansion coefficients 1 or 2 per cent.

Surface Tension

The values for the different saturants at 110 degrees centigrade are from 28.5 to 32.5 dynes per centimeter. The variations in surface tension with temperature, type of oil, and addition of resin are similar to the corresponding variations in specific gravity.

Electrical Properties

Dielectric Constant

For well-refined mineral oils, the variations in dielectric constant ϵ with temperature and with type of oil are accounted for by the corresponding variations in specific gravity.[6] This may be seen by comparing the dielectric constant curves for oils *O*-2, *O*-4, and *O*-8 in figure 3 with the specific gravity data in table IV. The addition of resin to oil increased the dielectric constant as is also shown in figure 3. Part of this increase is caused by the increase in specific gravity imparted by the resin, and the remainder by orientation of the polar resin molecules. The data indicate that the dipole moments of the ester *R*-7 and the polymerized resin *R*-8 are larger than the moment of pure abietic acid *R*-5.

The dielectric constants of the materials increased slightly (less than 5 per cent) during the aging tests. The changes in dielectric constants were roughly proportional to the changes in power factor which are discussed later.

Power Factor

The power factor-temperature curves of the oils are plotted in figure 4. Although there are large percentage differences in the values for the different oils, all the values

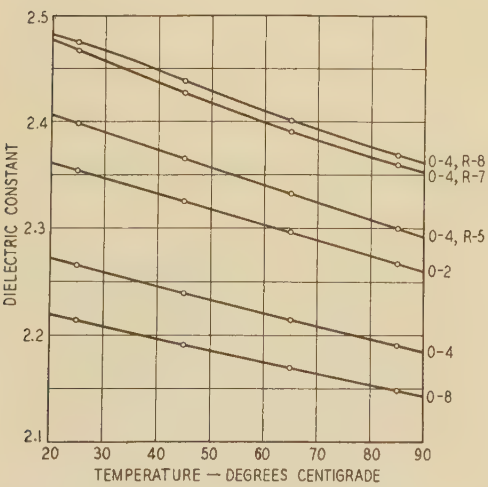


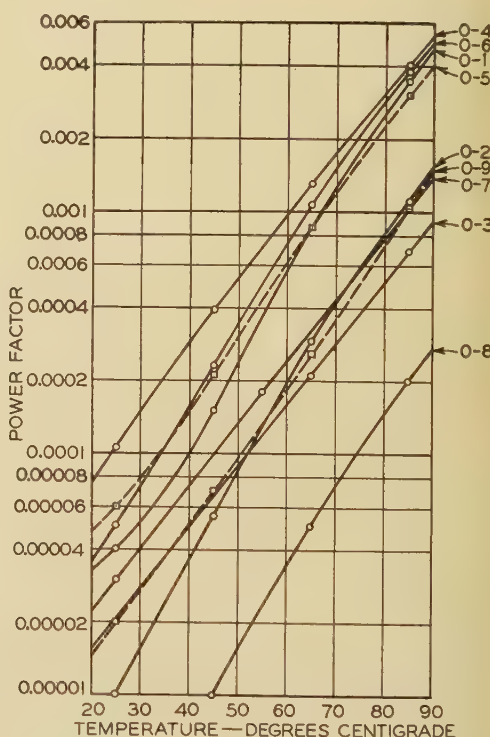
Fig. 3. Dielectric constant-temperature curves of oils and oil-resin mixtures (15 per cent resin)

are less than 0.004 at 85 degrees centigrade which is satisfactory for cable manufacturing purposes. These curves show that the relative increases in power factor per degree centigrade are about 6 per cent.

For a given oil, there is an approximately inverse relationship between the power factor and the viscosity, as has been shown by Kirch and Riebel[5] and Whitehead.[7] Compare figure 4 with figure 2. For this reason oils of high *viscosity ratio* often possess relatively steep power factor-temperature curves. It will be shown later, however, that relative steepness of the curve of the saturant has little effect on the curve of the saturated paper unless the absolute value of the saturant power factor at 85 degrees centigrade is high.

The effect of adding resins to oil on the power factor is shown in figure 5. It will be seen that if the resin contains oxidized constituents (*R*-2, *R*-6) or volatile constituents (*R*-3, *R*-7), the power factor of the resulting oil mixture is greater than that of the oil alone. This increase in power factor is especially large for oils which dissolve much of the oxidized resin as shown by the curve for *O*-3, *R*-2. If the resin has been largely freed of impurities (*R*-4, *R*-5), the power factor of the oil mixture is about the same as that of the oil alone. (Low power factors for purified resins in oils have also been reported by Kirch and Riebel.[5]) In some cases the addition of resin actually reduces the power factor, as may be seen by comparing the curves for oil *O*-9 with and without *R*-4. This may be due

Fig. 4. Power factor-temperature curves of oils



in part to the fact that some volatile constituents are driven off in the mixing operation, and in part to the reduction of the mobilities of conducting ions existing in the oil caused by the increased viscosity imparted by the resin. The power factors of oil-resin mixtures bear no relation to the acid numbers.

Conductivity

Values of a-c conductivity are related to the 60-cycle power factor thus, $\lambda_{ac} = 3.33 \times 10^{-11}\epsilon\delta$. Whitehead[7]

has noted that the ratio of a-c conductivity to long-time d-c (final) conductivity may be high for new oils, but is low for deteriorated oils. This has been confirmed in the present work, in which d-c measurements were made at 85 degrees centigrade on the saturants. Typical data are given in table V. Included in the table is the conductivity at one minute after voltage application, a measurement widely used in commercial insulation tests. This value lies between the a-c and final values, but at 85 degrees centigrade it is generally nearer the final value. The ratios of a-c to one-minute conductivity are from 1.2 to 3 for the new oils, but are usually only a few per cent greater than one for aged oils. For oils aged in contact with many metals, the ratios are also little more than one, but for oils aged with lead, the ratios are higher, often about 2. If the oil contains moisture, the ratio is high; if the oil is then aged slightly, the a-c conductivity decreases while the final conductivity increases. The addition of resin to oil increases the final conductivity, even when it decreases the a-c conductivity.

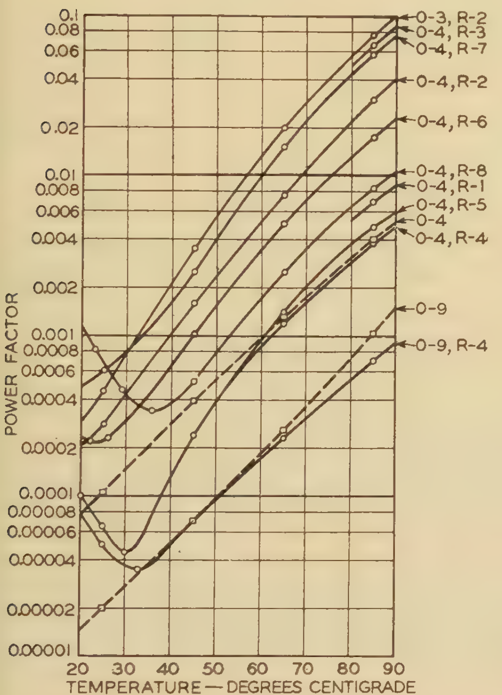


Fig. 5. Power factor-temperature curves of oil-resin mixtures (15 per cent resin)

Power Factor of Impregnated Paper

The effect of variations in the saturant properties on the power factor of impregnated paper was investigated. Power factor-temperature curves of a high density paper impregnated with various saturants were determined, some of which are shown in figure 6. The typically flat power factor-temperature curve of the dried, unimpregnated paper is also shown. It is seen that if the saturant has a low power factor (either a straight oil or a mixture of an oil and a purified resin), the curve for the saturated paper is similar to that for the dried paper. If the saturant has a high power factor (either a straight deteriorated oil or a mixture of an oil and an impure resin), the curve for the saturated paper partakes more of the nature of the curve for the saturant, exhibiting high power factors at the higher temperatures.

The conditions necessary for the existence of a functional relationship between the power factor of a given type of paper impregnated with various saturants and the saturant power factors were deduced from Whitehead's work on dielectric loss.[7] These conditions are that the saturant

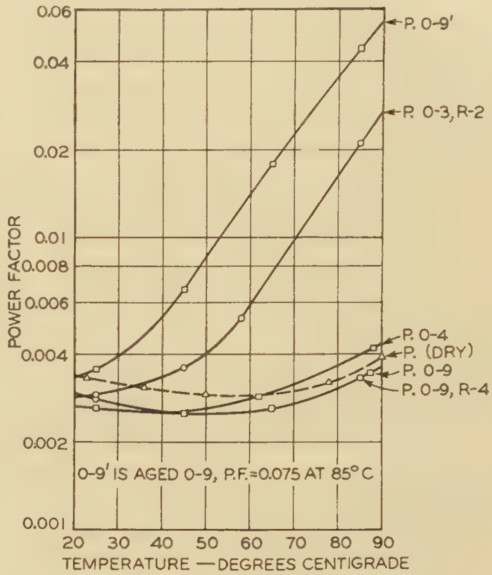


Fig. 6. Power factor-temperature curves of saturated paper

dielectric constants do not differ greatly and that *the saturants have equal viscosities*. For these conditions, values of saturant power factor δ_s and power factor of saturated paper δ_{sp} were read from the power factor-temperature curves. A family of curves of δ_{sp} versus δ_s was drawn, each curve corresponding to a certain saturant viscosity η, as shown in figure 7. It is apparent that δ_{sp} is not greatly affected by variations in δ_s below 0.003 at 85 degrees centigrade.

The curves in figure 7 are approximately of the form $\delta_{sp} = A + (B + C\eta)\delta_s$, where A, B, and C are parameters. A depends on the electrical properties of the paper, and B and C depend on the oil-to-paper ratio.

Oxidation Stability

From the data presented in figures 4, 5, and 6, it is apparent that the power factor of impregnated paper is sat-

Table V—Conductivities of Saturants at 85 Degrees Centigrade

Saturant	λ_{ac}	λ_1	λ_f	λ_{ac}/λ_1	λ_{ac}/λ_f
O-9 New	7.5	4.2	2.3	1.78	3.26
Aged 50 hours	6.8	4.1	3.0	1.66	2.27
New + 10 per cent *R*-4	5.8	3.5	2.6	1.66	2.23
O-4 New	29.6	21.0	16.3	1.41	1.82
Aged 100 hours	117	115	112	1.02	1.05
Aged 100 hours (lead)	208	127	119	1.64	1.75

λ_{ac} = a-c conductivity; λ_1 = one minute conductivity, λ_f = final conductivity
Unit = 10^{-14} mho per centimeter

isfactory throughout the cable operating temperature range if the saturant power factor is satisfactory at 85 degrees centigrade. Consequently, in studying the oxidation stability of cable saturants, it is important to follow the changes in power factor at 85 degrees centigrade.

The oxidation test data are presented in the form of power factor versus time-of-aging curves. In these curves a slow rate of rise of power factor with time of aging indicates a high stability to oxidation.

The aging curves obtained for the 9 oils are shown in figure 8. Oils *O*-1 and *O*-3 (of the light acid refined type), which contain appreciable amounts of certain types of residual constituents, are seen to be poorest in oxidation stability. Oils *O*-5, *O*-6, *O*-7, *O*-8, and *O*-9 are more stable, the stability being proportional to the degree of refining. Most of these more stable oils were refined by recently developed processes which yield highly paraffinic oils (see table I). It should be pointed out, however, that naphthenic oil *O*-2 and paraffinic oil *O*-4, refined by similar acid processes, have nearly the same stability. This suggests that naphthenic oils are not inherently less resistant to oxidation, and that their stability might be improved if better methods of refining them were used.

The oils which are poorest in oxidation stability also have the greatest solvent powers for impurities, and are therefore most susceptible to contamination.

The effect of adding various resins to oil *O*-4 on the oxi-

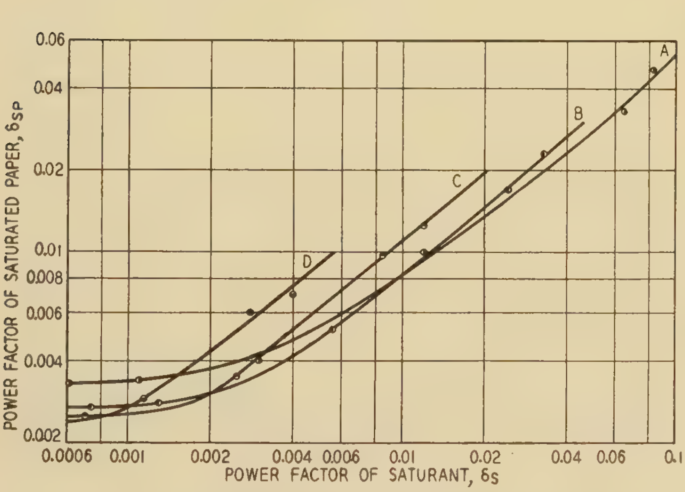


Fig. 7. Variation of power factor of saturated paper, δ_{sp}, with saturant power factor, δ_{sp} for various saturant viscosities, η

Curve	η—Poises	Approximate Temperature—Deg C	Approximate Equation of δ_{sp}
A	0.5	85	$0.0033 + 0.48\ \delta_s$
B	1	71	$0.0027 + 0.60\ \delta_s$
C	2	58	$0.0025 + 0.84\ \delta_s$
D	4	47	$0.0024 + 1.22\ \delta_s$

dation stability is shown in figure 9. The power factor of the oil mixed with the impure resin *R*-2, although higher than that of the oil initially, changes but little with aging, and is much less than that of the oil alone after aging. The power factor of the oil mixed with the purified resin *R*-4 increases but slowly from its low initial value with aging. Such stabilization of the oil is also produced by additions of the resin esters *R*-6 and *R*-7 and the polymerized resin *R*-8, although to a lesser extent.

In the series of resins *R*-2, *R*-4, and *R*-5, the stabilizing value decreases somewhat with increased purification. The partially purified resin *R*-4, however, is nearly as effective as the unpurified resin *R*-2, for part of the apparent effectiveness of *R*-2 is due to the fact that some of the originally dissolved oxidized constituents sludge out during aging.

The oxidation stabilities of all types of mineral oils is improved by the addition of resins, as may be seen by comparing the aging curves for the mixtures of *R*-4 with the oils, figure 10, with the curves for the oils alone, figure 8. Each oil-resin mixture has a useful life which is about 5 times that of the corresponding oil alone.

There are often large and varying departures from linearity in the power factor versus time-of-aging curves shown in figures 8, 9, and 10. If, therefore, the power

Table VI—Catalytic Powers of Metals on Oxidation of Oil O–4

Catalyst	Power Factor at 65 Degrees Centigrade: New	Aged	Increase	(Increase–0.005)/0.005
None	0.0013	0.0063	0.0050	
Pb	0.0013	0.0183	0.0170	2.4
Cu	0.0013	0.040	0.039	6.8
CuO	0.0013	0.026	0.025	4.0
Cu-CuO-Pb	0.0013	0.084	0.083	15.6
Cd	0.0013	0.0138	0.0125	1.5
Sn-plated Cu	0.0013	0.0079	0.0066	0.32
Sn-plated Cu (scratched)	0.0013	0.0080	0.0067	0.34

1,100 cubic centimeter samples of oil aged at 65 degrees centigrade for 176 days. Surface area of metal strips = 105 square centimeters

factors before and after 100 hours of aging are analyzed alone, as is often done in evaluating the oxidation stability of liquid dielectrics, false conclusions may be drawn.

Catalysts

When the oils were aged in contact with copper, lead, and steel strips, the catalytic effect of the metals accelerated the rate of power factor change for most of the oils, as may be seen by comparing the aging curves in figure 11 with those in figure 8. The rates of deterioration of the 2 oils of lowest viscosity index, *O*-1 and *O*-2, were not accelerated, but slightly retarded. This result was carefully checked.

The presence of metals in oil-resin mixtures did not change the rate of deterioration. This may be due to the fact that the dissolved oxygen was consumed near the surface of these mixtures. It at least indicates that the resins do not readily form harmful compounds with metals.

A study was also made of the relative catalytic powers of metals on the deterioration of oil. In these tests the aging temperature was reduced to 65 degrees centigrade so that the ordinary chemical combination of dissolved oxygen with the body of the oil would be reduced to a low value, and so that most of the oxidation would take place at the

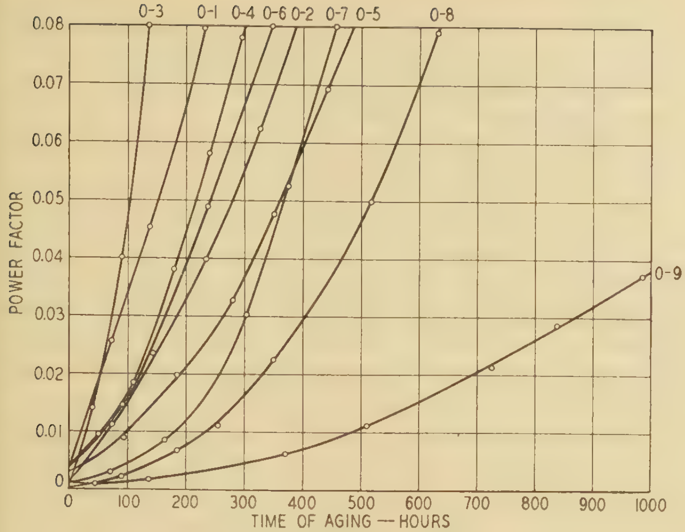


Fig. 8. Straight oils

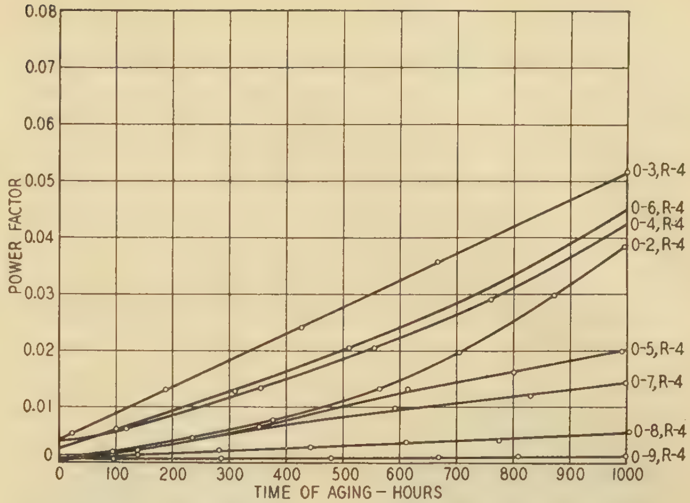


Fig. 10. Ten per cent mixtures of resin R-4 in oils

Fig. 9. Fifteen per cent mixtures of resins in oil O–4

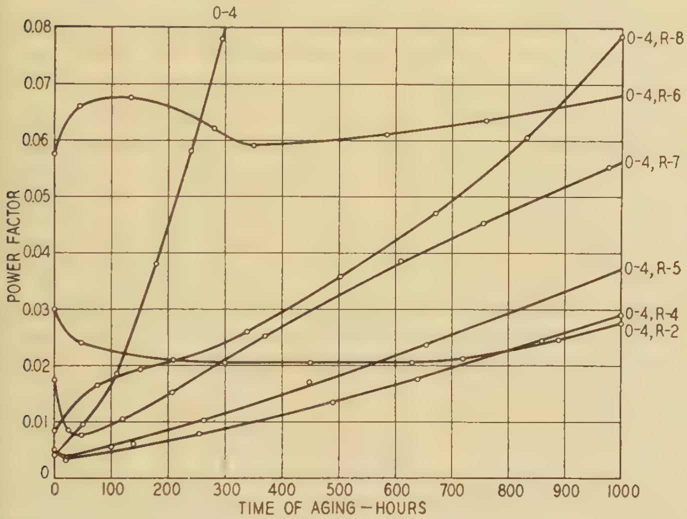
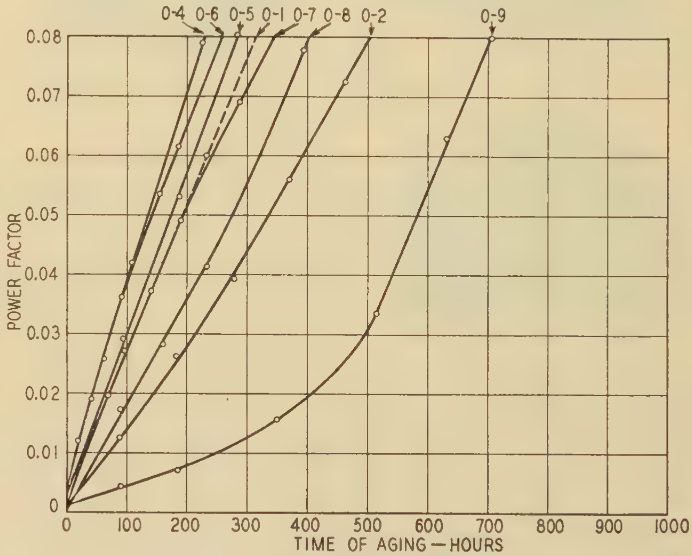


Fig. 11. Straight oils in contact with Cu, Pb, Fe



Figs. 8–11. Oxidation stability of saturants. Curves of power factor measured at 85 degrees centigrade against time of aging at 120 degrees centigrade

metal surfaces. The differences in catalytic effects of the metals were thus accentuated. It was found that the power factor versus time-of-aging curves were nearly linear and so only the initial and final values are given in table VI. It is of interest to note that the catalytic effect of copper is 21 times that of tin. The presence of dissimilar metals in contact causes little or no additional effect through battery action, because the absolute conductivities of the oils are very low.

Effects of Gaseous Ionization

In the tests for the determination of stability to gaseous ionization, the applied electric stress produced highly energized gaseous ions in the voids. These ions, on striking the saturated paper at the ends of the voids, caused chemical changes in the materials. The changes were chiefly polymerization and condensation of the saturant molecules, leading to the formation of the familiar "*X*" or wax and to the evolution of gas. Chemical changes involving gas molecules also occurred under certain conditions.

Wax Formation and Gas Evolution

Some of the wax patterns obtained in the tests are shown in figure 12. It is apparent that there is a large variation in the tendencies of the oils to form wax. A correlation was found between the wax formation, expressed in arbitrary units, and the viscosity index of the oils. This is indicated in figure 13. The correlation is nearly as close as the probable error in estimating wax formation, some 10 per cent, even though the oils studied are of different types and methods of refinement. Oils rich in naphthenic or residual constituents are much more resistant to gaseous ionization than the highly paraffinic oils. Figure 13 indicates also that the addition of resin to oils increases the stability to ion bombardment, at least for the more paraffinic oils.

The data plotted in figure 13 are the amounts of wax at

the ends of the artificial voids. For most of the compounds this was the only wax formed. But for oils of very low viscosity index, both with and without resin, wax was also present on the surfaces of the paper sheets at other places. If the total wax were considered, the wax formation versus viscosity index curves would be U-shaped, the values at very low viscosity indices being too ill-defined to be indicated.

No gas evolution was detectable in the ionization tests performed with hydrogen gas present. A small amount was observed when CO_2 was used, but this was independent of the saturant. There is evidence that this gas evolution was due to the breaking down of CO_2 into CO and O in the regions of very high stress at the electrode edges. Part of the evolved oxygen entered into the wax formation at the electrode edges, but not in the artificial voids. No significant changes in power factor of the saturated paper occurred in the ionization tests carried out under CO_2 or hydrogen.

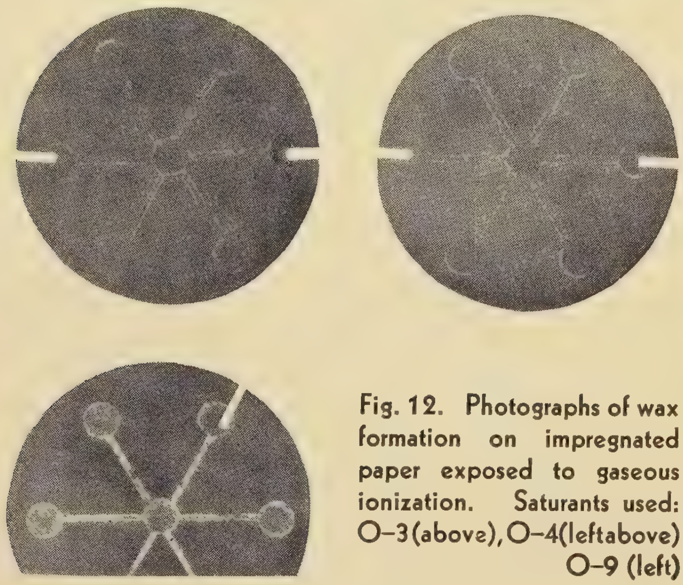


Fig. 12. Photographs of wax formation on impregnated paper exposed to gaseous ionization. Saturants used: O–3 (above), O–4 (left above) O–9 (left)

The results of preliminary tests in which saturants in a glass cell under high vacuum were subjected to electric stress indicate that the gas evolution varies with the viscosity index of the oil and the addition of resin in a manner similar to that depicted by the curves in figure 13, except that the range of variation is much less.

Combined Ionization and Oxidation

When gaseous ionization tests were carried out under reduced air pressure instead of under an inert gas, it was found that the gas pressure in the cell decreased with time. This took place at room temperature only when voltage was applied and ionization occurred. This indicates that the glow discharge facilitates the combination of oxygen with cable saturants by what might be termed an "electrocatalytic" action. This is substantiated by the fact that the wax formed in these tests was much greater in amount and darker in color than that formed in the tests with inert gases. Also, the power factor of the impregnated sheets increased markedly during the tests under reduced air pressure, although this effect was much smaller for resin-containing saturants than for straight oils. The data are given in table VII.

Gaseous Ionization Pressure

Gaseous ionization in insulation voids, in addition to promoting chemical changes, was observed to exert a physical pressure on the insulation surrounding the voids. One manifestation of this pressure is that much of the wax formed in the oil films on the paper surfaces at the ends of the voids was forced to the edges of the voids where the ionization was less severe. This can be observed in the wax patterns in figure 12. Another manifestation, which was most pronounced after very long periods of ionization, is that some wax was forced through the paper sheets in the direction of the field. It is likely that ionization pressure was responsible for the effects observed by Proos,[8] namely, that the displacement of saturants away from regions of high stress in cables was greater with simultaneous application of voltage and heat cycles than with application of heat cycles alone. It is also likely that the ionization pressure, by forcing the saturant from the paper, facilitates the formation of the microscopic carbonized paths through paper which have been found by Robinson[3] to be sufficient to initiate a "treeing" mechanism resulting in eventual breakdown of the cable insulation. In order that the tendency of the ionization pressure to force the saturant through the paper may be resisted without the application of hydrostatic pressure, as in the oil-filled cable, it is necessary that the paper be dense and that the saturant be high in viscosity and surface tension, and strongly adsorbed by cellulose.

Discussion

The observation made in the ionization stability tests that the gas evolution from oils of low viscosity index is less than that from oils of high viscosity index may be explained by the fact that the former oils contain more residual constituents than the latter (see table I). The residual constituents of the oils include aromatic compounds. Compounds of this type, although simpler in character, were found to evolve less gas than simple paraffinic compounds in the early tests carried out at the Detroit Edison laboratory.[9] It has also been recently shown by Nederbragt[10] that additions of small amounts of aromatic compounds to mineral oils are sufficient to lower the gas evolution considerably. The explanation usually given for this is that much of the gas, chiefly hydrogen, which is evolved instantaneously is reabsorbed by the double bonds in the molecules of the aromatic compounds. Since the molecules of the resins discussed in this paper also contain 2 double bonds, the reduction in gas evolution by resin additions to oils is also explained.

The majority of the molecules comprising the paraffinic and the naphthenic constituents of oils do not contain double bonds. It is possible that, on exposure to ionization, it is easier for hydrogen atoms to be detached from the open chain groups which form a large part of the structure

of the molecules of the paraffinic constituents than from the ring groups which predominate in the molecules of the naphthenic constituents. This would be a basis for explaining why the oils of very high viscosity index polymerize to form wax more readily than the oils of lower viscosity index, and why petrolatum, the molecules of which consist almost entirely of open chain groups, waxes even more readily than highly paraffinic oils.

The effect of resin additions in reducing wax formation is more difficult to explain. It is known from lubrication theory that a very small percentage of polar material added to a mineral oil can, by becoming adsorbed on metal surfaces, give a preferred orientation to the majority of oil molecules (non-polar) in the vicinity of the surfaces. Resin molecules, being polar, undoubedly become adsorbed by paper. This probably causes a similar preferred orientation of the oil molecules in the vicinity of paper-oil interfaces. The direction of this orientation may be such that those portions of the oil molecules which are exposed to the gaseous ion impacts are less vulnerable to their effects.

A comparison of the oxidation stability curves presented in figures 8 and 11 with the composition of the oils given in table I indicates that most of the paraffinic and naphthenic constituents and some of the residual constituents are stable to oxidation. The aromatic constituents are probably stable. The unstable residual constituents, which are usually dark in color, also render oil more susceptible to contamination.

The solvent refining processes commonly used in America in the production of lubricating oils of high viscosity index remove naphthenic and residual constituents which are stable to oxidation in addition to those which are unstable. These processes improve oxidation stability at the expense of greatly reducing the stability to gaseous ionization. In refining cable impregnating oils, processes should be used which remove only those constituents which are unstable to oxidation.

Oil oxidation products are hydrophilic, as shown by the spreading of aged oil on water. Many of them are acidic. They cause the high power factor of aged oils by dissociating to form conducting ions. Since all these properties are possessed by the oxidation products, it is sometimes concluded that all hydrophilic substances, especially acids, also have the property of causing high power factor, and that such substances should not be added to insulating oils,

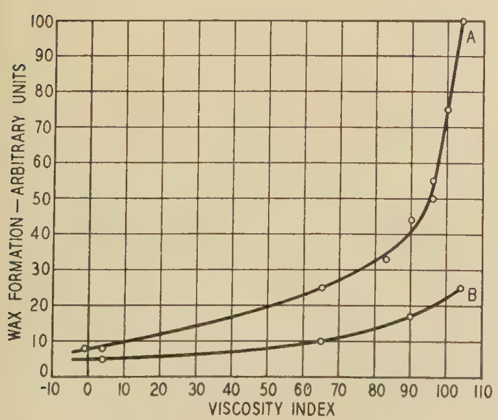


Fig. 13. Wax formation of saturants exposed to gaseous ionization as a function of viscosity index of the oils

A—Straight mineral oils
B—Oil-resin mixtures

at least not in large amounts. It has been shown in this paper, however, that certain purified resins, which are hydrophilic and acidic in character, are important exceptions to this hypothesis, for their presence in oils has little or no effect on the power factor. Moreover, the addition of these resins has been shown to be beneficial from the standpoint of stability.

The basic parent substance of the resins is abietic acid, which has the empirical formula, $C_{20}H_{30}O_2$. This substance is far less reactive than most organic acids, partly because of its high molecular weight and partly because of the way in which the acid group is attached to the molecule. This is why purified resin does not esterify readily or form harmful compounds (soaps) with metals, and why it has a low ionic dissociation constant (low power factor) in oil solutions.

There are several indications in the oxidation stability tests of oil-resin mixtures (for example, the data given in table VII) that the stabilizing influence of the resin is not due to a reduction in oxygen absorption, but to the fact that the resin oxidation products dissociate to form fewer conducting ions than do oil oxidation products. The data in figure 9, which show that crystalline abietic acid is

Table VII—Ion Bombardment Tests Under Reduced Air Pressure

Saturant	Oxygen Consumed, Cubic Centimeters	Wax Formed (Arbitrary Units)	Power Factor at 65 Deg C		
			Start	End	Increase
O-3	258	1,000	0.0032	0.0375	0.0343
O-9	215	1,000	0.0026	0.0416	0.0390
O-9, *R*-4	219	1,000	0.0026	0.0049	0.0023

nearly as effective as commercial resins in stabilizing oil power factor, indicates that most of the oxygen absorbed by the resins is taken up by the double bonds of the resin molecules.

Correlation With Cable Life

It may be well to consider a few results of cable life studies in connection with the results presented in this paper. Life tests made by Whitehead[11] and more recently by Race,[12] although under oil-filled cable conditions, showed that, other things being equal, specimens saturated with naphthenic oils had longer lives than those made with paraffinic oils. The saturants used in the solid-type cables having good service records have been found to be very stable to gaseous ionization. Resin-containing cables have established good service records, although the older types of resin-containing cables did not appear to advantage in some of the load cycle life tests made in the past. The writer believes this was mainly due to the exaggeration of the higher dielectric loss of these older cables under the accelerated test conditions which led to thermal instability, a fault of the test rather than of the cables. With an improved, less accelerated life testing technique, Halperin and Betzer[13] have lately found that

the use of resin in cables of recent manufacture has resulted in increased stability and life.

Conclusions

The results of the investigation may be summarized as follows:

1. Much valuable information can be obtained by subjecting cable saturants to various simplified tests and by correlating the results with viscosity index and chemical composition.

2. The addition of resin to mineral oils reduces migration of the saturant in cable operation without correspondingly increasing the time required for impregnation.

3. Oil-resin mixtures are not high in power factor unless the resin contains oxidized or volatile constituents.

4. The power factor of paper impregnated with mixtures of oils and properly purified resins is approximately the same as that of straight oil saturated paper.

5. For a given type of paper and for saturants of the same viscosity, the power factor of impregnated paper is a function of the saturant power factor.

6. Both naphthenic oils (low viscosity index) and paraffinic oils (high viscosity index) may possess good oxidation stability. The most stable oils now available are paraffinic.

7. The catalytic effect of metals on oil oxidation is greater for paraffinic oils than for nonparaffinic oils. The catalytic effect of copper is much greater than that of lead which in turn is much greater than that of tin.

8. The addition of resin to all types of mineral oils improves the oxidation stability as measured by power factor change.

9. Highly paraffinic oils are less stable to gaseous ionization than oils low in paraffinic constituents.

10. The addition of resin to oils containing some paraffinic constituents increases their stability to gaseous ionization.

11. Gaseous ionization in insulation voids exerts a pressure which tends to force the saturant from the paper.

12. Gaseous ionization in the presence of oxygen exerts an "electrocatalytic" effect on the oxidation of cable saturants. This results in a copious, dark wax formation and an increase in power factor which is less for resin-containing saturants than for straight oils.

References

1. Insulating Oils for High-Voltage Cables, T. N. Riley and T. R. Scott. IEE (Great Britain) *Journal*, volume 66, 1928, pages 805–30.

2. The M.I.T. Power Factor Bridge and Oil Cell, J. C. Balsbaugh, N. D. Kenney, and A. Herzenberg. Electrical Engineering, volume 54, March 1935, pages 272–9.

3. The Breakdown Mechanism of Impregnated Paper Cables, D. M. Robinson. IEE (Great Britain) *Journal*, volume 77, July 1935, pages 90–103.

4. Viscosity Variations of Oils With Temperature, E. W. Dean and G. H. B. Davis. *Chemical and Metallurgical Engineering*, volume 36, 1929, page 618.

5. The Dependence of Electrical Losses on the Viscosity of Saturating Media, E. Kirch and W. Riebel. *Archiv fur Elektrotechnik*, volume 24, 1930, page 353.

6. The Science of Petroleum (a book), chapter on dielectric constants by G. M. L. Sommerman. Oxford University Press, London (in press).

7. The Dielectric Losses in Impregnated Paper, J. B. Whitehead. AIEE Transactions, volume 52, June 1933, pages 667–81.

8. High Tension Cable With Solid and Fluid Insulation, C. F. Proos. Conférence Internationale des Grands Réseaux Électriques à Haute Tension, Paris, 1935.

9. Study of the Mechanism of Cable Deterioration, C. F. Hirshfeld, A. A. Meyer, and L. H. Connell. Printed but not published by the Association of Edison Illuminating Companies, 1929.

10. Generation and Absorption of Gas in Insulating Oils Under the Influence of an Electric Discharge, G. W. Nederbragt. IEE (Great Britain) *Journal*, volume 79, September 1936, pages 282–90.

11. The Life of Impregnated Paper, J. B. Whitehead. AIEE Transactions, volume 52, September–December, 1933, pages 1004–12.

12. Tests on Oil Impregnated Paper, H. H. Race. Electrical Engineering, volume 55, June 1936, pages 590–9.

13. Studies of Stability of Cable Insulation, Herman Halperin and C. E. Betzer. Electrical Engineering, volume 55, October 1936, pages 1074–82.

Distribution Lightning Arrester Performance Data

THE intelligent application of lightning arresters requires a knowledge of their performance characteristics under conditions which are likely to be encountered in service. Data have been presented relating to the impulse characteristics of insulation both as used on lines and in transformers. In order to know what protection may be secured with certainty in service, data are also required concerning the rates of voltage rise to be expected on distribution type arresters and the current encountered as a result of natural lightning. These data are being obtained, in some measure at least, through the use of impulse current measuring devices in series with arresters in service. Very little satisfactory information is available, however, with respect to the actual rates of potential rise, in fact most of such information is based on deduction rather than actual measurement.

It was necessary, some years ago, to arrive at a reasonable basis for comparing the operating performance characteristics of arresters, and standards were finally set up which admittedly are on a basis which is somewhat empirical. The test wave for arresters having a maximum permissible line to ground voltage of 6 kv or less is specified as 50 kv per microsecond, while the test wave for arresters having a maximum permissible line to ground voltage above 6 kv and including 15 kv is specified as 100 kv per microsecond.

Lightning arresters have not only a breakdown characteristic, but they also have in general a potential drop across the arresters due to the flow of current through the resistance in series with one or more gaps provided in the arresters. With all types of distribution arresters this potential drop, or *IR* drop as it is usually called, increases as

A paper prepared by the lightning arrester subcommittee of the AIEE committee on protective devices, and recommended for publication by the committee on protective devices. Manuscript submitted March 23, 1937; released for publication March 25, 1937.

Personnel of AIEE lightning arrester subcommittee: J. R. North, *chairman;* H. W. Collins, R. H. Earle, I. W. Gross, H. Halperin, C. F. Harding, K. B. McEachron, J. R. McFarlin, A. M. Opsahl, H. K. Sels, A. H. Schirmer, L. G. Smith, A. H. Sweetnam, and J. J. Torok.

Table I—Line Type Arrester Characteristics (3 Kv–15 Kv)

Arrester Rating—*Kv		Gap Breakdown—Crest Kv	Voltage (IR Drop) Across Arrester—Crest KV When Discharging Currents of 1,500 Amp	3,000 Amp	5,000 Amp
3	Max	22.0	13.5	15.5	17.5
	Ave	17.0	10.5	12.0	13.5
	Min	12 0	7.5	8.5	9.5
6	Max	45.0	27.0	30.0	32.5
	Ave	34.5	20.5	23.0	25.0
	Min	24.0	14.5	16.0	17.5
9	Max	64.0	40.0	44.0	48.0
	Ave	49.0	30.5	34.0	37.0
	Min	34.0	21.5	24.0	26.0
12	Max	75.0	52.5	58.5	62.5
	Ave	58.0	40.5	45.0	48.0
	Min	41.0	28.5	31.5	33.5
15	Max	86.0	65.5	73.0	78.0
	Ave	66.0	50.5	56.0	60.0
	Min	46.0	35.5	39.0	42.0

Gap breakdown taken on rate of voltage rise of 50 kv per microsecond for 3 kv and 6 kv arresters, and 100 kv per microsecond for 9 kv, 12 kv, and 15 kv ratings.
All arresters tested with a 10 x 20-microsecond wave.
The 60-cycle spark potential of all arresters shown in this tabulation will not be less than 150 per cent of the arrester rating.
* These ratings are maximum permissible line to ground root-mean-square voltages.

the current increases, but not linearly. Therefore, data relating to the potential across the arrester during the time of current flow are necessary for the proper evaluation of the long time protective ability of the arrester.

The present Standard requires a test current having a crest value of 1,500 amperes, with a rate of current rise of 150 amperes per microsecond and a decay to half value in a time not less than 10 microseconds. Certain tolerances are, of course, permitted. Since, however, the current values to be expected in practice are known over a considerable range of values, performance data at other current magnitudes than those specified in the Standard are required.

To make these necessary data generally available to the industry, the lightning arrester subcommittee has asked the manufacturers of arresters to submit information on their products, with respect to breakdown characteristics under standard rates of rise as outlined and *IR* drops for

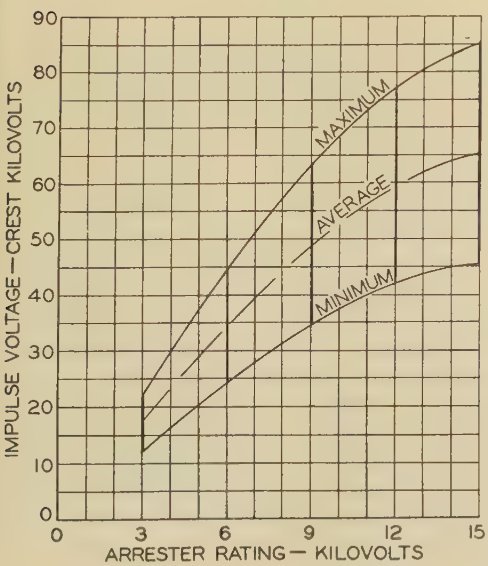


Fig. 1. Gap breakdown voltages, line type arresters

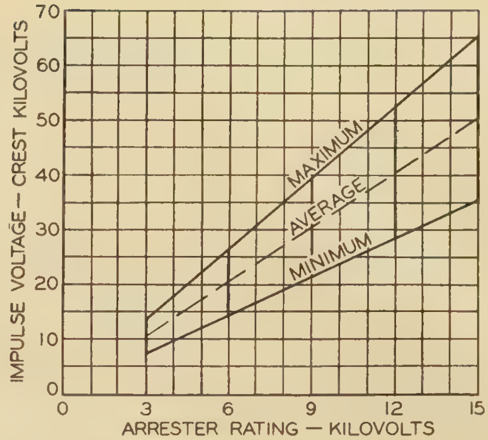


Fig. 2. IR drop at 1,500 amperes, line type arresters

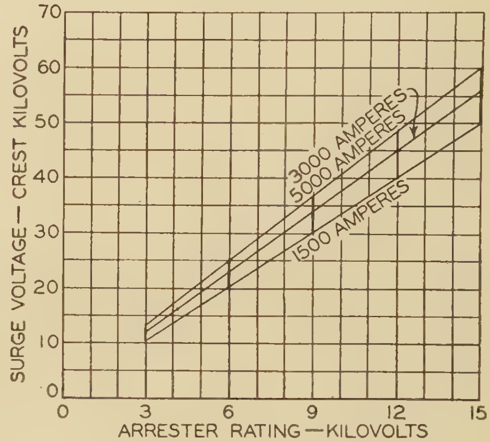


Fig. 3. Average IR drop, line type arresters

crest values of current of 1,500, 3,000, and 5,000 amperes. The manufacturers have supplied this information together with the expected tolerances in production. With these data available, table I and the accompanying graphs have been prepared showing the protective characteristics of line type arresters rated 3 kv to 15 kv.

The impulse breakdown data from table I are plotted in figure 1, showing not only average values, but also the maximum and minimum. Figure 2 shows the maximum, minimum, and average *IR* drop characteristics for the standard current wave of 1,500 amperes crest. The corresponding potentials across the arrester for 3 values of current are shown on figure 3. In each case where average values are given, they are the numerical average of the average value given by the manufacturers. The maximum and minimum values for each make of arrester were obtained by applying the tolerances given by each manufacturer to his average value. For each rating, the highest and lowest values of the maximums and minimums were selected as representing the total spread in performance characteristics.

It is hoped that these data as here presented will be of material assistance in determining the proper place of the lightning arrester as a protective device. The comparison between the surge voltages allowed by an arrester under various conditions and the performance characteristics of other apparatus associated with the arrester should lead to an intelligent evaluation of the protection provided by the arrester.

Coincidental Electric Drives

By L. E. MILLER
MEMBER AIEE

A "coincidental electric drive" may be defined as a drive consisting of several units of one machine, or a group of machines; each unit or machine driven by a separate motor. For successful operation, each unit or machine must have a speed bearing a definite relation to the speed of each of the other units. This speed relation may be constant or varying.

In operating a coincidental drive, 2 classes of speed must be considered, designated as primary speed and secondary speed. The primary speed is the speed of a group of motors as a whole. The change in this basic speed is of greatest importance, since the speed must be changed in order to change the output of material from the machine.

The secondary speed is that speed of any of the individual units, differing from the primary basic speed, and which accomplishes a successful degree of coincidence between the various units or machines in the drive. In operating a group drive, it is desirable to separate the means of accomplishing primary speed changes from the means of accomplishing secondary speed changes. With a-c motors, primary speed changes can be readily accomplished by changing the frequency, and, therefore, the basic speed of the whole system. On d-c drives, the primary speed change can readily be accomplished by changing the applied voltage, thus changing the basic speed of the whole system.

Secondary speed changes are much more easily accomplished in d-c drives than in a-c drives, since changes may be accomplished by change in field strength of individual motors. Due to the ease with which this secondary change may be accomplished on d-c motors without affecting primary speed changes, d-c motors are used more frequently in coincidental drives than are a-c motors.

To consider drives consisting of 2 or more motors which must operate in a different speed relation to each other, a review is desirable of that which basically determines the speed at which any motor, a-c or d-c, will operate. A clear understanding may be possible if the subject is approached from the standpoint of torque required and torque produced by the motor. If, at any instance, the torque produced by the motor exceeds the torque required, the excess torque will result in acceleration of the motor. If the torque required is in excess of the torque produced, the motor will decelerate. The acceleration or deceleration will continue until the torque balance is established.

If there is a change in certain of the electrical values, such as the voltage on d-c motors, or the frequency on a-c motors, the speed will certainly be affected, because these changes in electrical values will have an effect upon the torque produced. This change in speed, either upward or downward, will continue until the torque balance is again established. If the torque demand changes, an unbalance will result and there will be a speed change either upward or downward, which will result in such a readjustment of the electrical factors as to accomplish the torque balance; at which point there will be no further change. This method of approach requires no distinction between a-c or d-c motors, and is universal in its application.

The torque of either a d-c or an a-c motor is represented by the following equation: Torque = a constant $\times$ number of conductors in the rotor $\times$ flux per pole $\times$ the current per rotor conductor $\times$ the cosine of the angle between the stator and rotor flux. (In the case of a d-c motor this cosine is 1.)

In either an a-c induction motor or a d-c motor, a reduction in the speed of the rotor results in an increased rotor current with a consequent increased torque, other conditions remaining the same. (In the case of an a-c motor, this resulting increase in torque continues only until the breakdown torque of the motor is reached.)

Coincidental electric drives are very largely used in the handling and processing of material. If, during the handling or processing, there is no elongation or contraction of the material, it is quite obvious that each unit or machine must operate at such a speed as to handle the same length of material per minute. If there is elongation, each following section or machine must handle a longer length of material per minute. If the speed of the following section is too slow, loops will develop. If the speed of the following section is too fast, excessive tension will be produced in the material, possibly resulting in slippage or breakage. The process may require the reeling of material on a spindle with a constant rate of delivery of the material in the reel. The speed of the reel must decrease in proportion to the increased diameter of material and reel.

Considering again the definition previously given for coincidental electric drives, it can be seen that this definition may be expanded to cover a number of drives used in industry. For convenience, such coincidental drives may be grouped under 4 headings:

True or Exact Coincidence

In such a drive, the various motors may operate at exactly the same speed. The electric clocks throughout the country may be considered as an illustration of this type of coincidental drive. Another illustration is the use of 2 motors, each driving one-half of a leaf bridge. Still another and quite interesting illustration is the remote control of a steering gear on a ship by means of a synchrolock.

A paper recommended for publication by the AIEE committee on general power applications. Manuscript submitted March 5, 1937; released for publication March 31, 1937.

L. E. Miller is electrical engineer with The Reliance Electric & Engineering Company, Cleveland, Ohio.

Adjusted Coincidence

This group covers those drives where some modification of true coincidental relation is required, but after this relationship has been established, it becomes fixed and does not change. This may be illustrated by a sectionalized paper machine drive where there is some draw or shortening of the paper due to the drying process.

Approximate Coincidence

This heading is used to cover those drives where various units operate at approximately a fixed speed relation, but where for short periods there may be a considerable departure from coincidental speed with the final recovering of the over-all coincidental relation. A textile range with storage boxes furnishes an illustration of this type of drive, as does also a continuous pickling line with storage pits.

Instantaneous Coincidence

Under this heading may be classed a drive where the desired speed relationship between the different units is constantly changing at a predetermined rate of change. One of the more interesting cases of instantaneous coincidency in practical application occurs in the winding of strip material on a reel and maintaining approximately constant tension at the time. In such cases, coincidency between the mill and the reel must be maintained from the time the strip is first drawn taut by the reel until the strip leaves the mill, but as can readily be seen, the relations required for coincidency change inversely as the diameter of the roll of material changes.

In drives of this type, it is not only necessary to obtain coincidency in speed, but it is also desirable to obtain uniform tension during the reeling of the material. This uniformity of tension has been especially stressed in the reeling of metallic strips in order to obtain more accurate strip and to obtain this result with less annealing between rollings. Slipping clutches have been used in the past on many such drives, but since they fail to function as well as desired, and since they do not even approach uniform tension, there has been a constant demand for other and more accurate means of accomplishing the results desired.

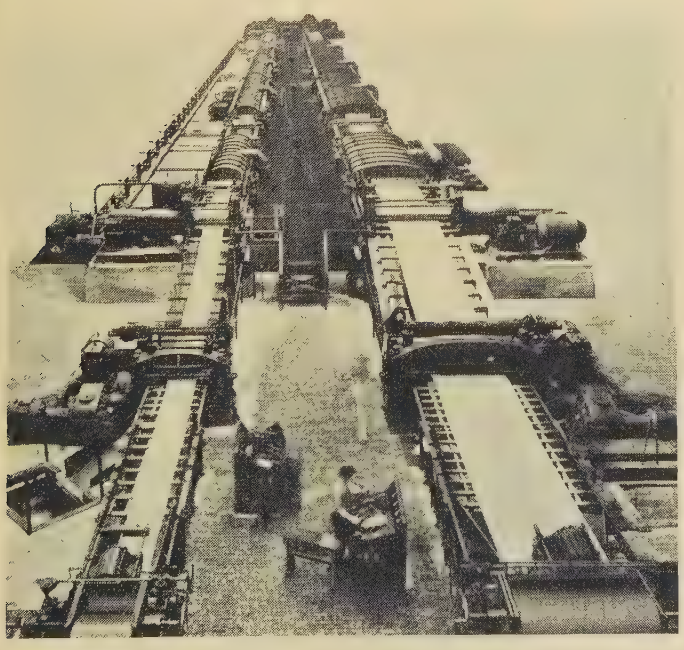


Fig. 1. A continuous pickling line illustrating an application of approximate coincidence

The ideal condition for an application of this sort is obtained when the torque produced by the driving unit varies directly with the diameter of the roll on which the material is being wound, and since the diameter of the roll varies inversely with the speed at which the roll must rotate, we arrive at the conclusion that the torque of the driving unit must vary inversely with the speed at which the driving unit operates.

A d-c motor, having its armature current maintained constant by varying its field, fulfills this requirement for all practical purposes, since as is shown in the torque equation, its torque varies directly with its field strength, and its speed varies inversely with its field strength. The problem in producing such a drive, therefore, becomes one of producing a regulator which will automatically maintain a constant current in the armature of a d-c motor by adjustment of the field strength.

An ideal type of regulator should:

a. Respond rapidly to changes in current, and adjust its rate of response to the current change required.

b. Continue its change in the field strength until current change is entirely corrected.

c. Respond to small changes of current.

d. Respond properly to either an increase or decrease in current.

e. Make minimum change in field strength to get proper correction in current.

f. Be sufficiently dampened in action to prevent causing surging.

Various types of regulators have been used in maintaining constant current on such applications. Of these, the following four are the most common. Each has given satisfactory results.

1. The vibrating type relay having one or more contacts connected across fixed resistors was probably the first type used.

2. A motor-driven rheostat, with the direction of armature rotation of the regulator controlled by relays responsive to the current in the reel driving motor armature, was developed as early as 20 years ago.

3. A regulator consisting of vertical stacks of graphite or carbon plates with silver inserts near one end arranged to tilt by the action of a torque motor, which is responsive to the current of the armature of the driving motor, has been used on many applications.

4. The regulator with which the author is most familiar is sufficiently different from the regulators previously mentioned, to merit a more detailed description. It is felt that in this regulator are incorporated those features of a good regulator previously mentioned. This regulator consists of a control motor and a rheostat which is in series with the shunt field of a driving motor. The rheostat is made up of a number of resistance tubes having a large number of taps. These taps are connected to a commutator. A slip ring is mounted at one end of this commutator and this ring is electrically connected to the last tap of the rheostat. Thus it can be seen that the commutator and ring form parallel electrical paths.

The control motor, in its mechanical construction, is quite similar to a small d-c motor except that it has 2 separate and distinct windings on the armature; each

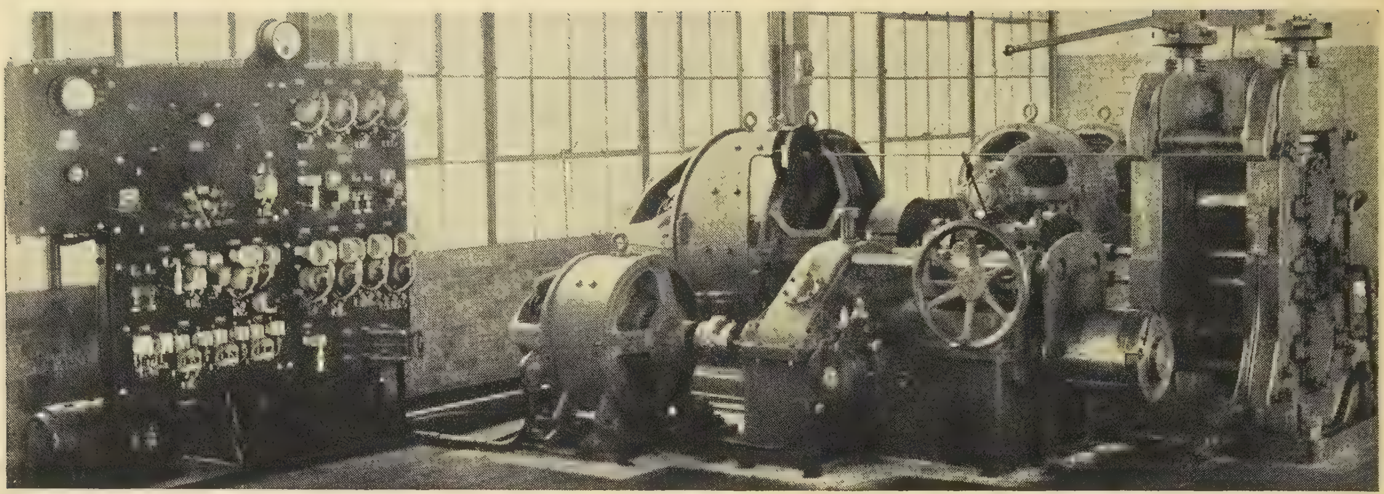


Fig. 2. A mill and wind-up reel illustrating an application of instantaneous coincidence. Strip is delivered directly from the mill to the reel

winding being connected to its own commutator. One winding, referred to as a spring or reference winding, consists of a large number of conductors of a small cross-sectional area. This might be considered as a very slow speed motor winding. It is connected in series with a resistance across a constant potential line. It gives the effect of a very long spring capable of being extended an infinite distance without changing the force produced.

The second winding is referred to as the torque winding, and consists of a fewer number of turns of a larger cross-sectional area. This winding might be considered as an ordinary high speed motor winding. It carries a definite proportion of the current passing through the armature of the motor being regulated.

The armature with its 2 windings operates in the flux field of a conventional d-c motor, and hence, current passing through either or both of the windings tends to produce rotation of the armature. The shaft of this combination armature has an arm mounted on it which carries 2 brushes electrically connected to each other, but insulated from the arm. One of the brushes rides upon the commutator of the rheostat mentioned before, and the other rides upon the slip ring which is electrically connected to one end of it. The result of one complete revolution is to change the condition of the rheostat, step by step, from a condition of full resistance to a condition of zero resistance.

The windings of the control motor are so connected that the current passing through the torque winding causes rotation in a direction tending to reduce the resistance in the rheostat, while current passing through the spring or reference winding causes rotation in a direction tending to increase the resistance in the rheostat. Thus, it can be readily seen that a condition of balance can be obtained which will cause a stationary condition of the armature, but when this condition of balance is disturbed by a change in the current in the torque winding, a rotation causing a corrective change in the rheostat will be produced. This rotational correcting action will continue until correction is established.

In regulating devices performing a function similar to that described there is frequently a tendency to hunt or to cause hunting on the part of the motor they are controlling. This is especially true of devices which tend to give true correction, and where the strength of the response to change is, as it should be, proportional to the change in current. This, of course, can be eliminated by dash pots, frictions, clock escapements, and other mechanical means. All such means, however, introduce friction which reduces the sensitivity of the regulator, since the frictional part of the retarding force is the same regardless of whether a small or large correction is indicated.

To remove this possible cause of trouble, a copper cylinder surrounding the armature of the control motor is introduced. This serves as an effective dampener and does not reduce the sensitivity for small changes in current. When the change in current is small, the rotation is slower, and the dampening action is negligible. When the change is current is large and the tendency to respond is greatly increased with the possibility of over-running and causing hunting, the dampening action from the cylinder is increased as the square of the change in speed of the control motor.

Referring to figure 4, we have a simplified schematic diagram showing the connections for a typical application making use of a regulator such as described. A generator *G* is connected mechanically to a mill for processing material. This generator *G* supplies a source of potential

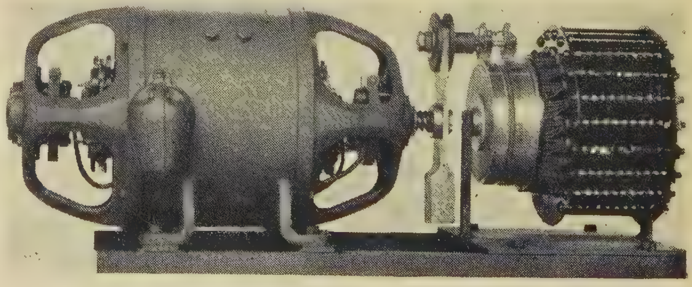


Fig. 3. A constant-current regulator of the type described in the context. The cover has been removed from the rheostat to give a clearer view

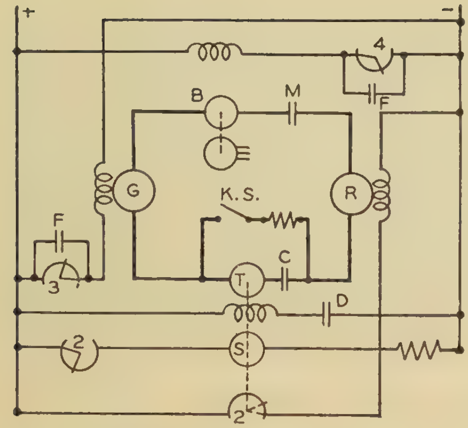


Fig. 4. Simplified schematic diagram of connections as used with the regulator described

R—Reel motor
G—Main generator
B—Booster generator
T—Torque winding
S—Spring winding
M—Main line contactor
C—Torque winding contactor
1—Tension rheostat
2—Regulator rheostat
3—Main generator rheostat
4—Booster generator rheostat
D—Regulator field rheostat
F—Field rheostat shorting contactors

to operate a reel motor *R*. Connected in series with the generator *G* and reel motor *R* is an independently driven booster generator *B*. This generator *B* supplies current to the reel motor when the generator *G* is stationary, and thus maintains a tension on the material between the mill and the reel, when the mill is shut down while material is still being processed.

Since the generator *G* operates at the same speed as the mill, the normal speed of the reel motor *R* will be such as to give the same lineal speed of take-up material as is being delivered by the mill. Adjustments from the normal speed of the reel motor *R* to accommodate the build-up of material on the reel are automatically produced by the regulator rheostat.

The torque winding *R* of the regulator, parallel with an adjustable resistance, is connected in series with and between the generator *G* and the reel motor *R*. The spring winding *S* of the regulator is connected in series with a fixed resistor and an adjustable rheostat across a source of constant potential. The regulator rheostat 2 is connected in series with the shunt field of the reel motor *R* and across a constant potential. Major changes in tension, produced by changing the current at which the regulator functions, are caused by changing the adjustable resistance paralleled with the torque winding, and minor or vernier changes are accomplished by changing the rheostat in series with the spring winding.

The operation of the regulator is such that once the balanced condition is predetermined and set, an increase in current will cause the torque of the torque winding to overcome the torque of the spring winding, and the rheostat arm will be moved in a direction to increase the field strength of the motor being regulated. This motion will continue until correct current is established. A decrease in current will have an opposite effect, and motion will be in the direction of decreasing the field strength.

In studying regulators, such as the one described and others, we should not be misled into thinking that we have absolute accuracy of tension at all times. A motor is not a meter, and even a meter is not absolutely accurate. By this we do not refer to the calibration inaccuracy which is common with most meters, but rather, due to its dampening and inertia, to its lack of instantaneous accuracy. In a motor we have similar inaccuracies considerably magnified. For instance, in a motor we have a dampening action due to the inductance of the armature circuit. Also, we have present an inertia not only of a motor armature, but also of the mandrel on which the material is being wound, as well as the material on the mandrel.

No method has as yet been developed that will maintain constant tension by the use of a regulator or other device during the accelerating or decelerating period. It should be pointed out that extra current is necessary during the accelerating period. However, since the accelerating rate will vary from time to time, and the frictional losses will be more or less variable, the extra torque for acceleration can bear no fixed relation to the torque required to produce tension; and the current cannot be determined with any degree of accuracy. On the other hand, it is generally desirable to cause, either by the regulator or other control devices, extra current to flow during the accelerating period. The reverse of this is true during the decelerating period.

In view of the fact that it is difficult to determine by watching meters just what is taking place in one of these wind-up drives, it would seem that a better study could be made by the use of undamped oscillograph readings. Such readings have been made on a typical application of a drive of this sort.

Oscillogram figure 5 shows the speed, armature voltage, armature current, and field current. The film was taken during the final period of winding a coil from strip steel. The armature voltage is apparently quite steady. The speed shows, as it should, a steady decrease. The field current shows indications of vibrations of small amplitude and a steady increase in value. This again is more or less normal. The armature current shows variations of small amplitude, and the maximum change in value is about 5 per cent. This does not come, as can be noted, in the form of a gradual increase from the beginning to the end of the process, but occurs only as infrequent peaks or valleys. The mean change appears to be not exceeding 3 per cent.

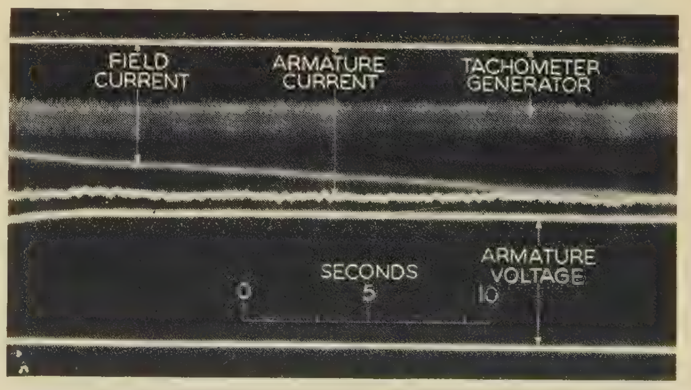


Fig. 5. Oscillogram obtained during the winding of strip steel into a coil. Shows gradual rate of change of motor field current and speed, and approximately constant armature current and voltage

Oscillogram figure 6 is a continuation of oscillogram figure 5 carrying the build-up to very close to its final value. The characteristics are the same as in figure 5. It is impossible to see the rheostat steps in the field current curve, since there are 180 steps in the rheostat, and the change per step is only about 0.04 inch on the original 6-inch wide film. From the film we find that the regulator responded rapidly enough to keep the current from varying to any great extent from the predetermined value, and the response was not so rapid as to give any tendency toward a hunting condition. Visual observation bore out the fact that the regulator did not over travel, and, therefore, did not have to correct itself by returning from a too advanced position. This test was made on a reel driven by a 100-horsepower 3- to 1-speed range motor. The build-up on this particular coil was such as to cause the motor to operate through a speed range of 2 to 1, and required about $^3/_4$ of the normal full load rating.

In attempting to get as much of a complete run as possible on one oscillograph reading, the film was, of necessity, run at a very slow speed. In doing this, however, as can be noticed, the peaks and valleys of the armature current reading were so bunched together as to make an almost solid line. A further study was desired in order to bring more plainly into view the actual fluctuations of the armature current. Figure 7 shows the results of this study. In this case the film speed was increased to about 6 inches per second, as can be seen by the timing wave made from a 60-cycle power supply. Here the curve of armature current was sufficiently elongated to give a very definite view of the peaks and valleys separated from each other. On this curve, the armature voltage shows 2 very definite frequencies, one a comparatively low frequency with a change of not very great amplitude, and another a quite high frequency with a change of an even smaller amplitude. The ripple of vibration in the voltage curve does not seem to bear any particular relation to the ripple found in the armature current curve, but no doubt, has some influence on it. Another fact which may have had some influence in causing a variation in the armature current was noted in watching the actual winding up of the strip upon the mandrel. The catch for securing the strip to the mandrel projected beyond the periphery of the mandrel, causing an eccentric shaped coil. This was only a minor eccentric-

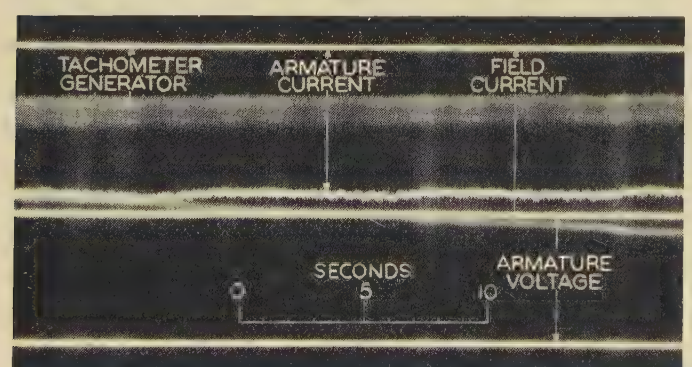


Fig. 6. Continuation of figure 5. The coil has now approached its maximum size

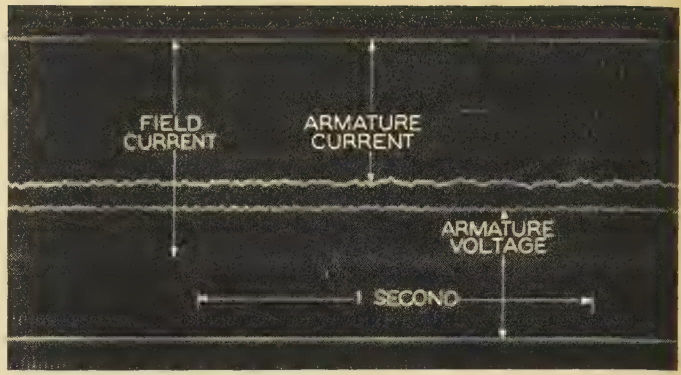


Fig. 7. A higher speed oscillogram of the same operation as figures 5 and 6. Peaks and valleys occurring in armature current are shown in more detail

ity, and while theoretically it had some effect upon the armature current, we are not justified in concluding that it was the entire cause of the ripples occurring therein.

In considering an application of this type, there is still another inaccuracy present which should be recognized; namely, the frictional losses in the motor, gears, and reel. When operating near the normal load, this inaccuracy is for all practical purposes negligible, but when operating at very low loads, as may be the case when only one mill and reel are available to cover a wide range in tension, this inaccuracy can easily become very material.

As an example of this, let us assume the current required to produce the torque to overcome friction is 10 per cent of the normal current rating of the motor, and let us assume that current variation permitted by the regulator is 5 per cent, as shown in oscillograph figures 5, 6, and 7. Then if the current required for overcoming friction and producing tension is 100 per cent of the normal rating, the variation in tension will be $5/(1.00 - 0.10) = 5.56$ per cent, which is a very good result. If, on the other hand, the current required to overcome friction and produce tension is assumed to be 20 per cent of the normal rating of the motor, then the variation in tension will be $5/(0.20 - 0.10) = 50$ per cent. This may be satisfactory on many applications, but is certainly too great on many others, and seems to indicate the possibility of unsatisfactory operation in attempting to make a mill and reel cover too great a range in tension. It is the author's belief that a 5 to 1 range in tension is as high as is practicable in an application of this type.

Conclusion

Coincidental electric drives are being used more and more in industrial applications. Many such drives have been applied with insufficient knowledge of the actual requirements of those drives, and with insufficient study of the details of that which must be accomplished to produce a successful drive. Some of these drives are now working with passable, although not entirely satisfactory, results. Improvements, both as to economy and operation, can be expected in the future by the study of those drives already applied, and by continued effective co-operation between the operating and manufacturing engineers.

Impulse Operation of Magnetic Contactors

By CARROLL STANSBURY
MEMBER AIEE

Magnetic contactors as commutating devices for the application of power for very brief periods (as in resistance welding practice) have encountered limitations which have been considered inherent in their nature. The author has found that this is not necessarily the case, and describes a method of operating magnetic contactors which to a great extent avoids the usual limitations and gives short periods of great accuracy.

THE MAGNETIC contactor has been one of the most important factors in the application of electricity to industry. Although its most extensive use in the past has been in motor control, another application of great and growing importance in recent years has been in the resistance-welding industry. The duty which the contactor is called on to perform in this field is the commutation of a single phase circuit of low power factor, with loads ranging from 1 or 2 kva up to over 1,000 kva. The periods of power application vary from 2 or 3 cycles up to one second or more (references 1, 2, 3, 4).

There are certain very important classes of resistance welding, however, on which it has been found essential to use periods of power application which are too short for the use of magnetic contactors by conventional methods. Such welding includes the welding of aluminum alloys, stainless steel, and various light welding of nonferrous metals in small light parts where the extreme localization of heat resulting from short-time welding is advantageous, (reference 5). The timing periods involved are on the order of 1 or 2 cycles or even $^{1}/_{2}$ cycle in some cases.

Cam-operated contactors driven by synchronous motors have been used for this purpose and also all-electronic controllers using thyratron and ignitron tubes have been widely applied (references 6, 7, 8, 9, 10). (Reference is here made to control for single spot welding as distinguished from the type of seam welding control which consists of a series of over-lapping spots applied at very high speed through roller electrodes.)

The magnetic contactor has not been able to enter this field successfully heretofore because certain limitations appeared to mark off a range of application below about three cycles to which it is not applicable. However, in the natural competition of ideas and practices it was inevitable that attempts would be made to overcome these limitations. The incentives for such attempts were considerable, provided magnetic contactors could be applied to this field with a simplicity and cheapness comparable to that with which they are applied to the less critical installations.

A paper recommended for publication by the AIEE committee on general power applications. Manuscript submitted March 4, 1937; released for publication March 17, 1937.

CARROLL STANSBURY is employed in the development department of Cutler-Hammer, Inc., Milwaukee, Wis.

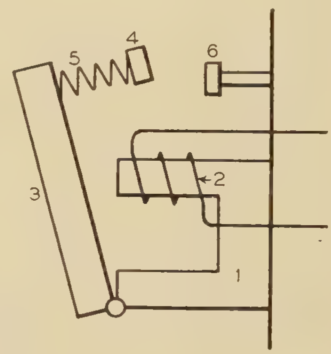
General Problem

It will perhaps best bring out the nature of the problem to suppose at first that power is to be supplied to a single-phase load in separate periods of 10 cycles duration. If a contactor of suitable size is selected and oscillograms relating magnet-coil current to the closed or open condition of the main contacts are examined, it is found that if the coil circuit is closed at a given instant, the main contacts will touch about 2 cycles later, and that the contactor magnet will seal about 2 cycles after that.

Fig. 1. Essential elements of typical magnetic contactor

Elements represented are: stationary magnet structure 1, magnet coil 2, armature 3, moving contact 4, contact spring 5, stationary contact 6

Magnetic blowout and return ("tail") spring omitted for simplicity



Similarly, in opening, the contactor requires about 2 cycles after the coil circuit is interrupted before the main contacts separate. To meet the above requirements, therefore, some sort of timing device is used which closes the magnet circuit for 10-cycle periods. Its contacts close 2 cycles before the main contacts touch, and open 2 cycles before the main contacts separate. For purposes of the present analysis it will be assumed that the timer used is non-synchronous in action. That is, the closing and opening of its contacts are at random relative to the phase of the alternating supply voltage.

The timing results obtained would be somewhat disappointing if accurately measured, for reasons which would include some or all of the following:

1. The timing device itself would probably have an error of $\pm{}^{1}/_{2}$ cycle or more

2. There would probably be a variable amount of arc on the pilot-device contacts, affecting the accuracy of commutation of the coil circuit

3. Due to the nonsynchronous closing and opening of the coil circuit of the contactor, variable transients would occur affecting the duplication of action of the contactor magnet

4. The use of a contactor with an a-c magnet involves having a direct iron-to-iron seal on the magnet face. The actual sealing

would be slightly different each time, which would affect the accuracy of opening of the contactor

5. There would be a variable amount of arc on the main contacts of the contactor.

None of these factors is serious at 10 cycles, but all become increasingly so as the required period is reduced. Experience has shown that 3 or 4 cycles is the lower limit for most applications, because the percentage variation in the energy input to the weld becomes excessive at shorter periods.

It is possible to set up a specification for an ideal program of energizing the contactor magnet simply by prescribing that the above defects should be absent. Such a specification would be something like the following:

1. The timing device proper must be accurate to a very small fraction of 1 cycle.

2. The pilot device must operate without arc.

3. The timing device must be synchronous in operation.

4. The contactor magnet must operate without direct iron-to-iron seal.

5. Arc on the main contacts must either be eliminated or be held to a uniform effect.

Accurate Timing Element

The essential elements common to practically all magnetic contactors are indicated schematically in figure 1.[1] It is immaterial for the present discussion whether the armature is hinged or slides, or whether it moves horizontally or vertically. The number of contacts and contact springs is also immaterial.

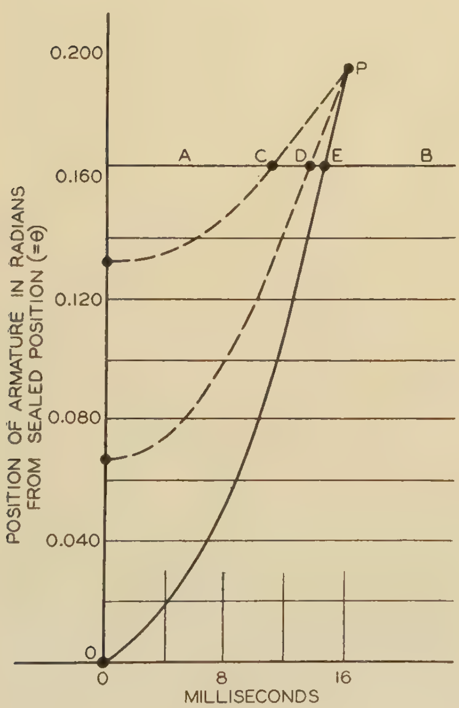


Fig. 2. Curves representing opening motion of magnet armature

In a typical magnetic contactor of average size the moving armature 3 is a laminated steel structure weighing several pounds. It constitutes as high as 85 per cent of the total mass which is set in motion by the magnet. In order to obtain fast operation for resistance welding and similar applications, design tendencies have naturally been toward reducing the moving mass, increasing the magnet pull by using intermittent duty coils, and increasing the opposing spring forces in contact springs and tail spring, if used.

When a magnetic contactor is energized, only part of the armature travel is completed when the contacts meet. Further forward movement of the armature is necessary (during which contact spring 5 compresses) to provide for contact wear and for magnet travel during opening before the contacts separate, so that suitable separating speed may be attained. Expressed briefly, armature movement equals arc gap plus wear allowance.

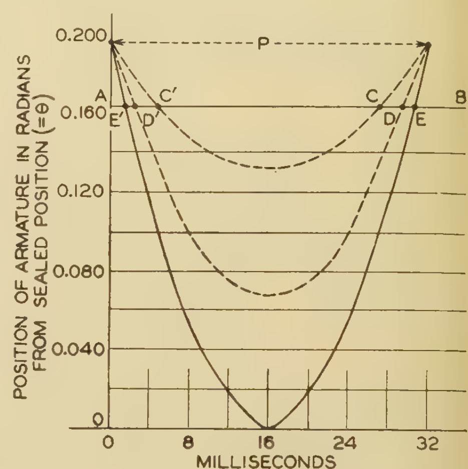


Fig. 3. Motion of armature during impulse operation of contactor

Assume that the magnet is holding its armature in the sealed position with the contact spring 5 correspondingly compressed and that the magnet is then de-energized. The resulting outward motion of the armature is that of a mass accelerated by a spring (frictional and gravity forces being small compared with that produced by the spring). Then if

I = moment of inertia of armature
T_s = initial outward torque due to contact spring
θ = angular travel of armature outward from sealed position
t = seconds after initial instant
K = reduction in contact spring torque per radian of opening motion

$$I\frac{d^2\theta}{dt^2} - (T_s - K\theta) = 0 \qquad (1)$$

The solution of this is (assuming $\theta = 0$ when $t = 0$):

$$\theta = \frac{T_s}{K}\left[1 - \sin\sqrt{\frac{K}{I}}\left(t + \frac{\pi}{2}\sqrt{\frac{I}{K}}\right)\right] \qquad (2)$$

If I is in pound-inches,[2] T_s in inch-pounds, K in inch-pounds per radian, and θ in radians:

$$\theta = \frac{T_s}{K}\left[1 - \sin\sqrt{\frac{12 \times 32.16K}{I}}\left(t + \frac{\pi}{2}\sqrt{\frac{I}{12 \times 32.16\,K}}\right)\right] \qquad (3)$$

Using equation 3, the angular motion of the armature may be plotted as a function of time as in figure 2, wherein the full-line curve shows the armature motion following

its release from the sealed position (the curves of figure 2 apply to an actual contactor which may be considered as typical).

Now if the armature were held at some position intermediate between the sealed position and that at which the contacts just touch, as at B or B^1, and released, equation 3 shows that the armature would move in accordance with the corresponding dotted curve of figure 2. It can be shown that these curves constitute a family all of which intersect at point P, which is the angular position

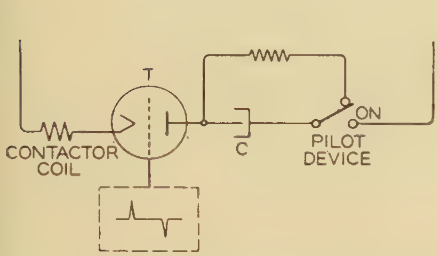


Fig. 4. Circuit providing actuating current impulse for contactor coil—charging type

at which deformation of the contact spring 5 is entirely relieved. However, in an actual contactor the contact spring 5 is restrained by a mechanical stop of some sort before this point is reached. As a result, the contact 4 is moved away from engagement with contact 6 at the angular position of the armature represented by the line A—B. The slope of the various curves at points C—D—E is proportional to the speed of separation of the contacts.

Evidently the process of acceleration of the armature by the spring is reversible. This fact is represented by figure 3. If the armature were in some way caused to move in the closing direction at an angular speed corresponding to the slope of the curve at E^1 at the instant the contacts engage, its movement thereafter would be in accordance with the full-line curve, and the total period during which the contacts would maintain a closed circuit would be represented by the interval E^1E. (This statement neglects friction losses, which experiment proves to be justifiable.) Similarly, a slower armature speed at the instant the contacts touch would result in movement in accordance with one of the family of dotted curves, with slightly reduced interval. The only reason the interval is reduced is the restraint of the contact spring, as explained above.

We are thus dealing with the inherent period of the mechanical system consisting of the contactor armature and the contact spring. The armature might be likened to the balance wheel of a watch, while the contact spring plays the part of its hair spring. Operated in this way the contactor is its own timing device.

If the mechanical arrangement were such that the armature could oscillate in both directions under influence of the spring, it can be shown from equation 3 that the period of full oscillation would be

$$2\pi\sqrt{\frac{I}{386K}}$$

Therefore the interval p in figure 3 is

$$p = \pi\sqrt{\frac{I}{386K}} \tag{4}$$

It would appear from the above that a contactor timed in this way is inherently inflexible as far as time adjustment is concerned. In fact it is the fixed nature of the timing which gives the system its inherent stability and reliability. Nevertheless, it is found to be a simple matter in practice to obtain timing adjustments over a sufficient range, as will be brought out in a later paragraph.

Actuating Impulse

It was assumed in the foregoing that the armature was in some way to be put in rapid motion prior to the instant the contacts touch. It was further assumed that the application of the accelerating force would not be continued after that instant. This could be done mechanically by the action of a motor-driven cam, by the sudden release of a compressed spring, by pneumatic means, etc., etc. However, it has been found most convenient and satisfactory to accomplish this by momentarily energizing the contactor coil by a single unidirectional pulse of current. A suitable current pulse for this purpose must be accurately reproducible and it must bear a definite phase relation to the a-c supply voltage. Other desirable characteristics will appear later in the description of the control. Apparently the simplest method of generating suitable current pulses is by the use of charging or discharging currents of capacitors.

Figures 4 and 5 show the 2 alternative circuits which have been successfully used in practice. It will be seen that both circuits involve a single-pole double-throw

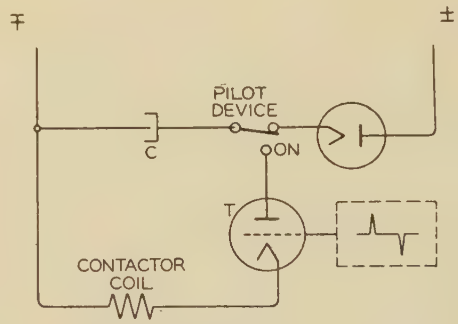


Fig. 5. Circuit providing actuating current impulse for contactor coil—discharging type

pilot device, a capacitor C, and a thyratron T. For either circuit, when the pilot device is put in the *on* position, these elements are connected in series with the contactor coil.

As the contactor coil has both resistance and self-inductance, the circuit of figure 4 (neglecting the action of thyratron T) is the classical case of L, C, and R connected in series with a d-c source (reference 11). (For the convenience of the reader, formulae appropriate to this type of transient are given in an appendix to this

paper, together with a brief description of the method by which the electrical and mechanical performance of a given contactor and circuit may be predicted.)

As is well known, if in the L, C, R circuit of figure 4, $CR^2 < 4L$ the current flow when the pilot device is closed will consist of a series of damped oscillations (or would, but for the presence of the thyratron T). This is illustrated in figure 6 which was made with the thyratron omitted. By way of comparison, figure 7 illustrates the case in which the constants are such that no current oscillations occur.

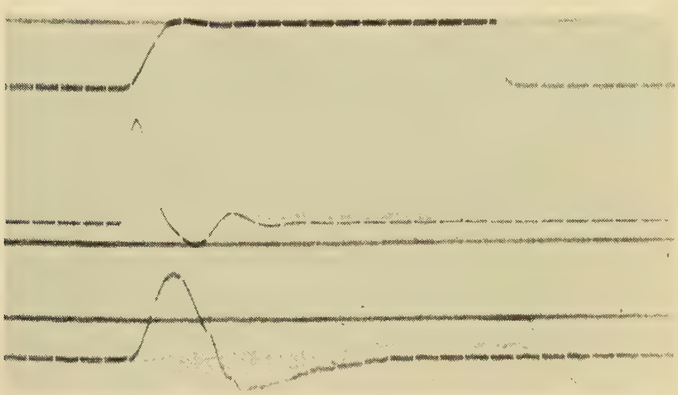


Fig. 6. Oscillogram of impulse operation of contactor

Actuating current as in figure 4, except thyratron omitted
Upper trace—Potential across capacitor C
Middle trace—Magnet-coil current
Lower trace—Magnet armature motion
Interruptions in trace are at one-cycle intervals

Examination of the type of current pulse in figure 6 or 7 shows neither to be well suited for the present purpose, which obviously requires for clean-cut operation a single pulse of current, without either subsequent smaller pulses as in figure 6, or gradual cutoff as in figure 7. The presence of the thyratron T (together with the use of suitable circuit constants) provides for such a pulse by preventing subsequent current flow after the first single half-oscillation. To show this figure 8 was made under the same conditions as figure 6 except for the presence of the thyratron in the circuit. Figure 8 and figure 9 are typical of actual operation with the charging and discharging circuits, respectively.

The thyratron also serves to time the start of the pulse to the desired synchronous relation to the a-c supply to the welder circuit. This triggering action is accomplished by applying a sharp-peaked wave to the grid to allow the thyratron to start conducting (after the pilot switch is closed) only at a definite point in the a-c cycle (reference 12). The phase position of the peaked wave is made adjustable throughout 360 electrical degrees to permit adjustment of the phase of the instant of separation of the contacts.

As explained in the caption of figure 6, the lower trace of each oscillogram shows the motion of the magnet armature. In each case, this trace is shown in relation to 2 horizontal lines, one of which represents the position of the armature with the contacts just touching, while the other represents its position when in the sealed position. These lines were made in turn by holding the armature in the touch and sealed positions, respectively, during a passage of the oscillograph film. The time interval between the 2 points of intersection of the trace of armature travel with the *touch* line therefore corresponds to the actual closed-circuit period. The portion of the trace between these points is equivalent to the curves of motion of figure 3. The quantitative agreement will be evident by comparing figure 8 with figure 3, the timing gaps in the former being at one cycle, or 16.7 millisecond, intervals.

It will be noted in the oscillograms that, after opening, the armature pulls out further than the position of rest and is then restored thereto in a period of about 4 cycles. This action is possible on this particular contactor because it includes a flexible stop in the open position which has a snubbing action of this type to prevent bouncing.

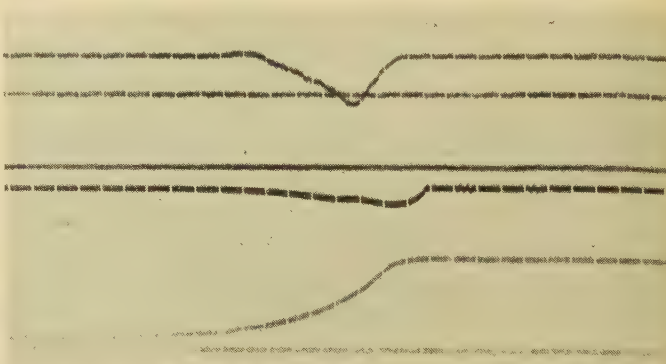


Fig. 7. Impulse operation with aperiodic actuating impulse

Circuit as in figure 4; $CR^2 > 4L$

The operation of the circuit in figure 5 is essentially the same as that of figure 4 except that operation is obtained on the discharge instead of the charging current. Figure 4 is suited for use on a d-c supply circuit whereas figure 5 is suited for a-c supply or may be used on d-c with the rectifying tube omitted.

Time Adjustment

From the explanation accompanying figures 2 and 3 above, it will be seen that adjustment of timing by mechanical means would be possible, either by use of weights attached to the moving armature, to increase its mass, by adjustment or interchange of contact springs, or both. In practice, however, entirely electrical adjustment by changing the capacity in the circuit is very much more convenient and desirable. Such adjustment results in variation of the speed of the armature at the instant the

contacts touch, and figure 3 shows that some time adjustment is available in this way, as the closed interval can be changed from E^1-E to D^1-D and so on. Furthermore, by providing more capacity than necessary for sealing the armature, longer periods than that represented by the interval E^1-D in figure 3 are available. Experience has shown that, by providing a nonmagnetic spacer to prevent an iron-to-iron seal on the magnet face, quite satisfactory accuracy for longer timing periods up to about 5 cycles is obtainable.

The greatest percentage of the work for controllers of this type is in the short range where the contactor operates on the true impulse basis. Where such short time with suitable accuracy is available in the controller, it is generally preferable to hold the time of application constant and adjust the energy input for different types of work by adjusting the welding current.

The performance curves of figure 3 and the oscillograms herein apply to a contactor having a somewhat higher natural period than would generally be applied to this work. Actual contactors now being used have lighter armatures and higher spring tensions and have a natural closed-contact period of about 1 cycle. Laminated magnets are necessary in order to obtain suitable speed.

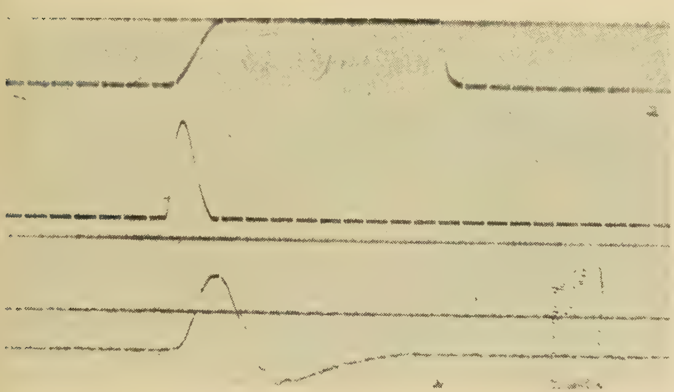


Fig. 8. Impulse operation with oscillation prevented by thyration

Circuit as in figure 4; $CR^2 < 4L$
This is normal type of impulse operation with the charging circuit

Arc on Main Contacts

Phase adjustment of the coil current pulse makes possible adjustment of the instant of opening of the main contacts to avoid objectionable arcing. It is possible to adjust away from a condition of heavy arc, and experience shows that the arc that is obtained is quite uniform and permits excellent uniformity of the welding results. On stainless steel and light nonferrous welding the arcing is not a factor, but it becomes important on the high currents used in aluminum welding.

Automatic means for adjusting the instant of opening of the contacts have been developed and successfully operated. Commercial installations used to date have, however, had manual adjustment only.

Commercial Applications

Figure 11 shows a commercial impulse controller using the circuit of figure 5. The contactor which is used with this control is of more or less conventional type as far as appearance is concerned, but has an unusually small magnet for the size and capacity of the contacts and has unusually high contact spring pressure in order to reduce its natural closed period to 1 cycle.

Commercial experience covers a period of about 18 months at the time of writing and includes separate installations in regular production service on stainless steel, aluminum, light nonferrous welding, and machine driven operation in one-cycle welding on steel at more than 5 welds per second. The method is particularly suited to applications of the last-mentioned type because operating without sealing the magnet eliminates the principal cause of magnet wear. Operation is quiet for the same reason.

Conclusions

The method of control described herein conforms to the specifications given in a early paragraph of this paper as essential for successful short period operation of magnetic contactors. Moreover, it results in a contactor control in which the noise of magnet impact, and the problem of magnet wear, are eliminated. The controls built on this principle have fulfilled expectations in service over a considerable period and on a variety of work.

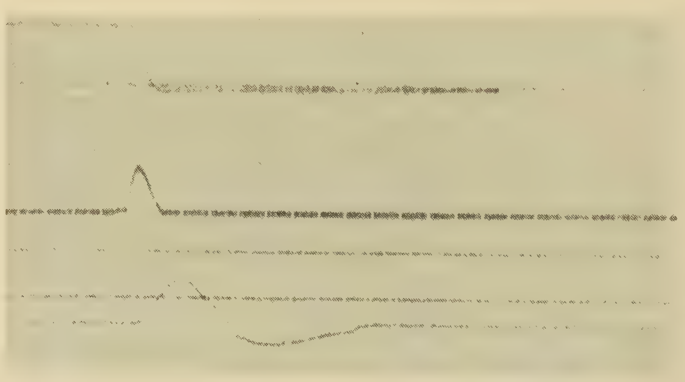


Fig. 9. Normal impulse operation with discharging circuit

Circuit as in figure 5; $CR^2 < 4L$

Although the present exposition of the method has emphasized its application to the resistance welding field, this is primarily for purposes of illustration and because that field appears to be the most important immediate application. It is quite possible that the method is applicable as a machine element for other purposes.

Appendix—Calculation of Armature Motion

In order to predict the performance of a given contactor in impulse operation, it is necessary to have the following information:

1. The self-inductance L and a-c resistance R of the magnet coil as a function of turns and of magnetic gap. (It appears to be a satisfactory approximation to use 1.5 times the d-c resistance for R)

2. The pull characteristics of the magnet as a function of ampere-turns and magnetic gap

3. The moment of inertia of the armature, contacts, and other moving parts, both when moving freely and after contacts engage. Calculated values based on estimated gyration radii of components are sufficiently accurate for practical purposes

4. Torque of unbalanced weight and friction torque of armature and other moving parts

5. Torque exerted by contact springs as a function of magnetic gap.

Symbols

i = instantaneous coil current, amperes
e = instantaneous potential across capacitor, volts
E = d-c supply volts in figure 4 or initial (fully charged) capacitor volts in figure 5
t = seconds from instant pilot device is put in on position
L = self-inductance of coil, henries
R = a-c resistance of coil, ohms

$$\beta = \sqrt{\frac{1}{CL} - \frac{R^2}{4L}}$$

Although for a given coil L is a variable depending on the magnetic gap, and although the armature is in motion during the passage of the pulse of coil current, analysis of a number of oscillograms of coil current and armature motion has shown that a good approximate prediction of the current pulse is obtainable by using for L the value corresponding to the armature at rest in the open position. Using this value of L it is essential, in order to obtain a circuit in which the current transient has an oscillating tendency, to make $CR^2 < 4L$. If this requirement is met by the circuit constants selected (reference 11),

$$i = \epsilon^{-\frac{Rt}{2L}} \cdot \frac{E}{L\beta} \sin \beta t \tag{5}$$

for either figure 4 or figure 5. Equations for potential across capacitor are, for figure 4:

$$e = E\left[\epsilon^{-\frac{Rt}{2L}}\left(\cos \beta t + \frac{R}{2L\beta} \sin \beta t\right) - 1\right] \tag{6}$$

and, for figure 5:

$$e = E\epsilon^{-\frac{Rt}{2L}}\left(\cos \beta t + \frac{R}{2L\beta} \sin \beta t\right) \tag{7}$$

By the use of equation 5 it is possible to plot an approximate curve representing the coil current pulse as a function of time for any assumed set of constants.

Having this prediction of coil current as a function of time and the other information listed above, it is a matter of straightforward mechanics to predict the motion of the armature. The method used by the writer for doing this is a step-by-step calculation in which the net torque and resulting acceleration is taken as constant for each of a succession of equal short periods of time (0.002 sec. has been found suitable for the time increments).

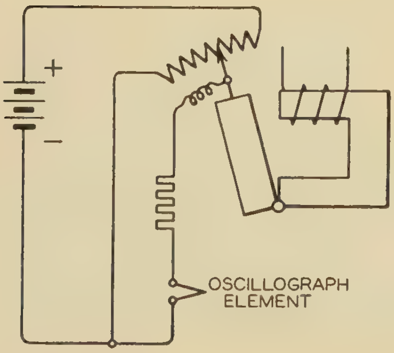


Fig. 10. Method of recording armature movement on oscillograms

The brush of the voltage-divider rheostat (mass and friction of which are negligible) is moved by the armature

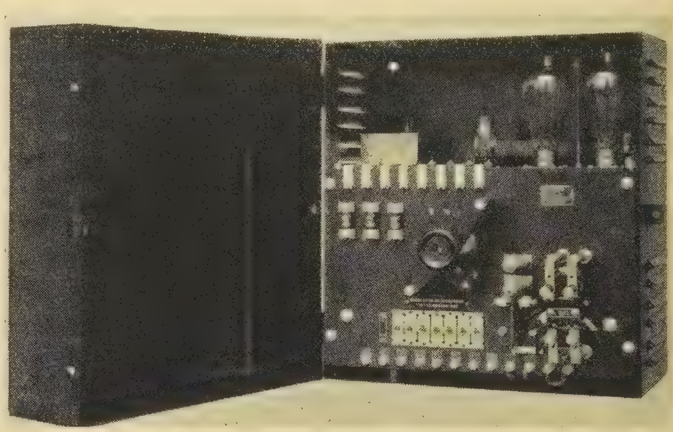


Fig. 11. Commercial controller for impulse operation of contactor

Contactor not shown; handwheel in center of panel is for phase adjustment; the row of snap switches is for adjustment of the main capacitor; relay and thermal strip timer allow time for heating of thyratron cathode

Bibliography

1. The Development of Resistance Welding Electrical Control Devices, R. L. Briggs. *Journal* of the American Welding Society, March 1934.

2. Timing of Spot Welders With Respect to Current Flow, D. C. Wright. *Journal* of the American Welding Society, December 1933.

3. Precision Spot Welding With Tube-Controlled Contactors, C. Stansbury. *Journal* of the American Welding Society, December 1933.

4. Development and Application of Automatic Welding Controls, H. W. Roth. *Journal* of the American Welding Society, December 1933.

5. Some Fundamentals of Spot Welding—Especially of the Light Alloys, R. H. Hobrock. *Metals and Alloys*, January, February, and March 1935.

6. Advances in Resistance Welding Made Possible With Thyratron Control, W. C. Hutchins. *Iron and Steel Engineer*, March 1933.

7. Thyratron Control of Welding in Tube Manufacture, Lord and Livingston. *Electronics*, July 1933.

8. A High Power Welding Rectifier, Silverman and Cox. Electrical Engineering, October 1934.

9. A New Timer for Resistance Welding, R. N. Stoddard. Electrical Engineering, October 1934.

10. New Development in Ignitron Welding Control, J. W. Dawson. Electrical Engineering, December 1936.

11. Introduction to Electric Transients, Kurtz and Corcoran. John Wiley and Sons, Inc., page 31.

12. Voltage Impulses for Thyratron Grid Control, M. M. Morack *General Electric Review*, June 1934.

A-C Motor Protection

By C. W. KUHN
MEMBER AIEE

Synopsis

An investigation of motor protection can be made by a comparison of the proper motor and thermal overload relay data. Convenient data for this are motor "protection" curves for comparison with "tripping time" curves of thermal overload relays. These motor curves should include single phase operation of polyphase motors as this is one of the abnormal conditions for which motors should be protected. The capacity of the motor at different expected ambient temperatures should be compared with the capacity of the overload relay at its corresponding ambient temperatures.

MOTOR PROTECTION is an important consideration in any a-c motor installation. This is recognized in industry by the almost universal use of motor protection. It is of particular importance in the design and use of automatic motor-driven equipment such as compressors, pumps, electric refrigerators, oil burners, and the like, which may represent definite fire hazards as the result of motor failure.

Almost all a-c motor protection today is by means of thermal overload devices. These thermal overload devices are not necessary units for the operation of the motors they protect but increase the use which can safely be made of them. Frequently they are not given the consideration they merit. This is partly due to lack of data, in convenient form, for the adequate consideration of a thermal overload application.

It is the purpose of this paper to outline the data necessary for a study of a-c motor protection by thermal overload devices and to present a method of calculating some of the more important factors based on the usual motor performance curves.

Motor Characteristics

The important motor characteristics to determine adequate motor overload protection are:

1. "Protection" curve
2. "Locked rotor data"
3. "Load" curve

"Protection" curves show the time required for the motor windings to reach a certain maximum safe temperature. Time values for these curves are preferably measured, starting with windings at 25 degrees centigrade. The temperature rise of the motor windings is conveniently measured by means of thermocouples placed in the motor slots. Figure 1*A* and figure 1*B* show "protection" curves for 2 designs of a-c motors. Curves are included for single-phase operation of polyphase motors. Such single-phase operation may result from a blown fuse and is one of the hazards against which polyphase a-c motors should be protected.

While the curves of figure 1*A* show that any protection satisfactory for polyphase operation would protect the motor when operating single phase, the reverse is sometimes true. Single-phase operation of some polyphase motors results in higher temperatures of the active winding than would be obtained for the same current with normal polyphase operation. This is an important factor in motor design and one which is not always given consideration.

"Locked rotor data" merits special consideration and should consist of the following particulars:

1. Current at normal voltage
2. Current at normal voltage of polyphase motors with only one phase in circuit
3. Time required to reach the maximum safe temperature for 1 and 2 starting with ambient temperature of 25 degrees centigrade

The motor "load" curve shows the continuous load in amperes at which the motor will reach a maximum safe

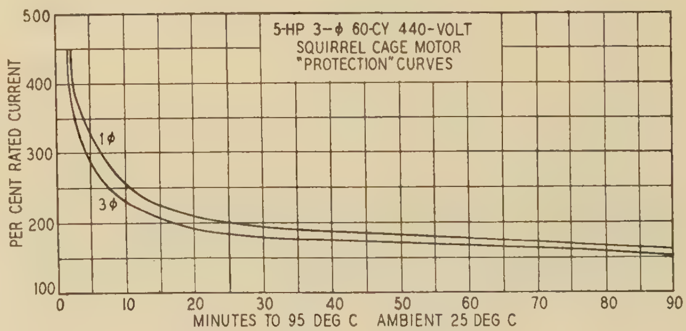


Fig. 1A

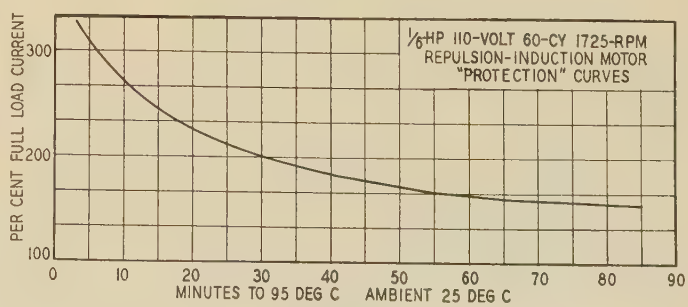


Fig. 1B

A paper recommended for publication by the AIEE committee on general power applications. Manuscript submitted January 4, 1937; released for publication March 1, 1937.

C. W. Kuhn is development engineer with Cutler-Hammer, Inc., Milwaukee, Wis.

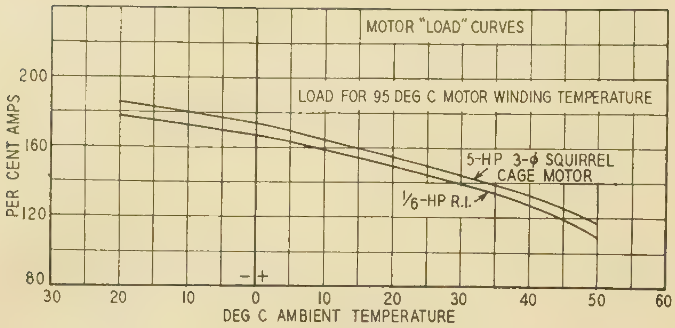


Fig. 2

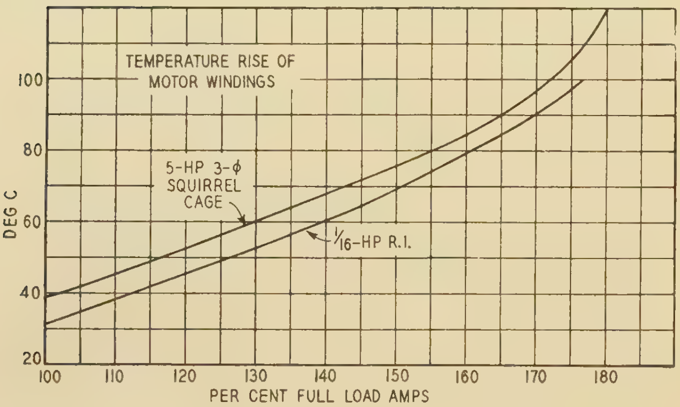


Fig. 3

temperature for various ambient temperatures. Such curves are shown in figure 2 for 2 designs of motors. Data for motor "load" curves can be obtained by determining the temperature rise of the motor winding for continuous operation at different loads as shown in figure 3. The permissible temperature rise at any ambient temperature is the difference between the selected maximum safe temperature and the ambient temperature considered.

Calculating Motor Temperature Curve

In the absence of actual test data, an investigation for determining motor protection can be made from the usual motor performance curves as shown in figures 4*A* and 4*B*. From these curves a "temperature rise" curve for continuous duty standard motors can be calculated on the basis of a 40 degree centigrade rise of the motor windings at full load. The current and watt loss causing this temperature rise can be obtained from the efficiency and current curves of the motor. The approximate temperature rise at higher current loading is proportional to the watt loss in the motor. A "temperature rise" curve calculated on this basis is shown in comparison with an actual test curve for the same motor in figure 5. From these data we can determine a motor "load" curve as previously explained.

Thermal Overload Relay Characteristics

Two important thermal overload relay characteristics for motor protection are:

1. "Tripping time" curve
2. "Tripping current" curve

The "tripping time" curve for a thermal overload relay shows the time required to trip the relay at various current values, in an ambient temperature of 25 degrees centigrade. One convenient method of varying the performance of the simple industrial thermal overload relay in this respect is by changes in heater coil design. Curves of figure 6 illustrate some possibilities in this respect. Curve *A* is suitable for the protection of most standard types of motors. Curve *B* shows the performance of a special fast tripping heater coil for the protection of the internal start type of motor. Curve *C* shows the performance of a special slow tripping heater coil for use with the more rugged types of motors with high-inertia starting loads.

To provide thermal overload relays whose operating characteristics more closely follow motor characteristics, designs can be used with additional heat-storage mass to assimilate the effect of the motor frame. Such designs, however, are not generally used for industrial or small-motor applications, their added cost being justified only on large generators and motors.

The "tripping current" of a thermal overload relay depends upon the ambient temperature in which it is operating. This is illustrated by the curves of figure 7. These further show a difference in the effect of ambient temperature as a result of different tripping temperatures of the thermal overload relays. For an ideal thermal overload relay design the tripping temperature should be

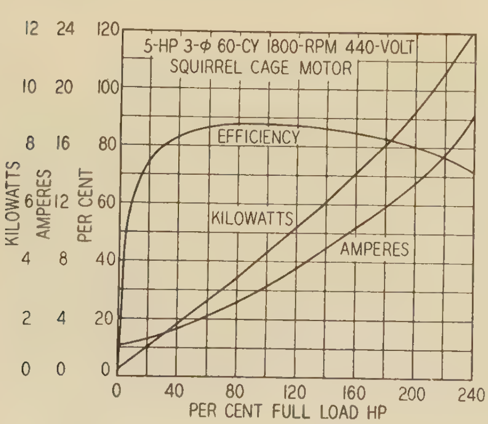


Fig. 4A

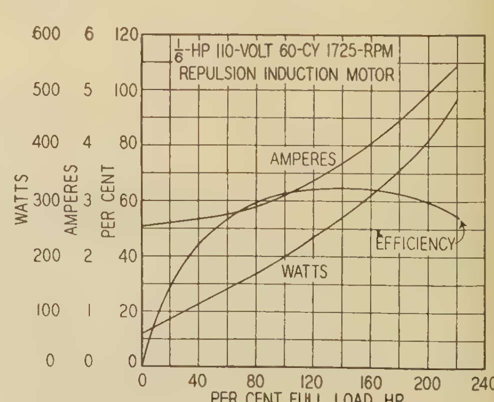


Fig. 4B

such that ambient temperature will change the tripping current to maintain a maximum, safe motor temperature.

The current rating of a thermal overload relay as established by the Underwriters Laboratories requires that it *must* trip at rated current in a 40 degree centigrade ambient temperature. Any manufacturing variation must be such as to cause it to trip at a value below its rated current.

Thermal Overload Relays

There are 2 general types of thermal overload relays used for industrial applications, i.e., bimetal and solder film. Each of these is manufactured in a variety of ingenious mechanisms. Similar performance can be obtained with either type, as to tripping temperature, time characteristics, etc. Either type can be made with or without current adjustment.

The solder-film type of overload relay is capable of current adjustment by movement of the thermal member with respect to the overload heater. The amount of current adjustment obtainable by this method is limited to approximately 20 per cent. A relay of this type is shown in figure 8. Another method of obtaining current adjustment with this type of thermal overload relay is by use of current transformers with variable taps and adjustment of the magnetic circuit.

Current adjustment is most readily accomplished with a bimetal overload relay by changing the movement (which changes the tripping temperature) required for the bimetal to trip the overload relay. An adjustable thermal overload relay of this type is shown in figure 9.

The chief advantage of the adjustable overload relay is the possibility of its use for motors of different current ratings. Current adjustment is unnecessary on a particular motor application. If the overload rating is proper for that motor, higher current adjustments are dangerous from the standpoint of motor burnout, and lower adjustments are unnecessary for motor protection. Two manual a-c starters with nonadjustable thermal overload units of the solder-film type are shown in figure 10.

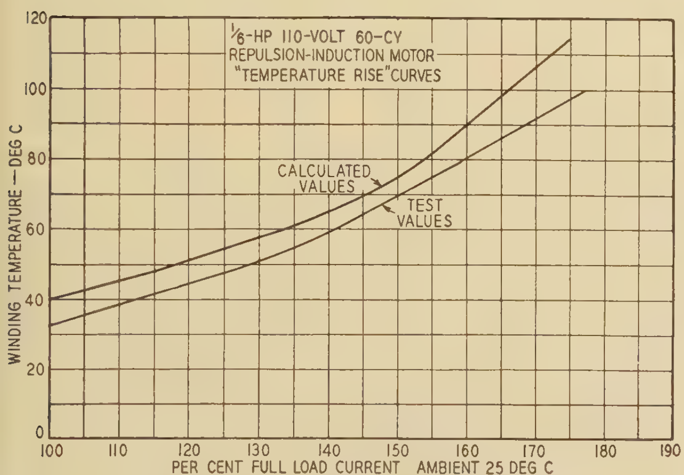


Fig. 5

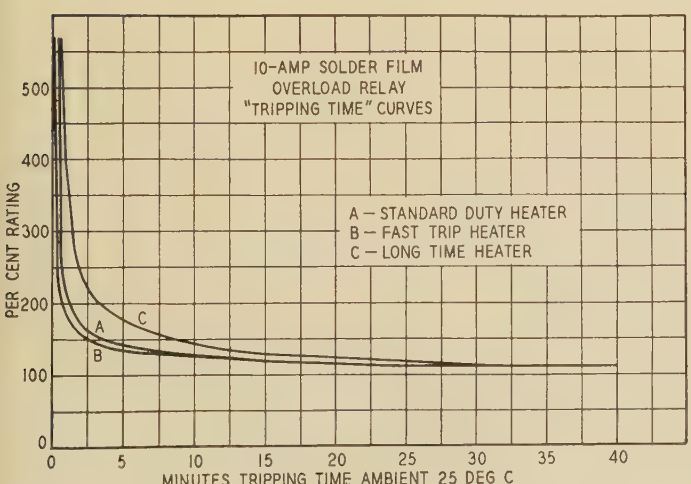


Fig. 6

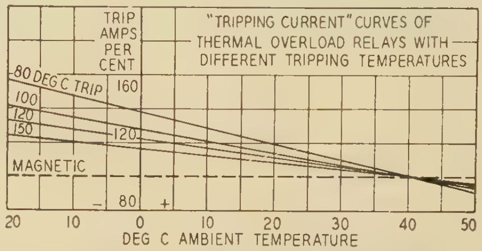


Fig. 7

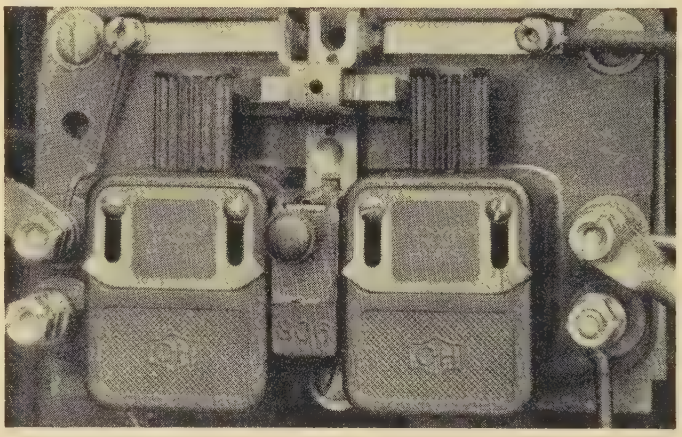


Fig. 8. Adjustable solder-film thermal overload relay (Cutler-Hammer)

Motor-Mounted Overload Devices

Overload devices built into the motor are at present receiving increased consideration, particularly in the small-motor field. These devices are of the same general type as the separately mounted overload units and should be distinguished from those operating primarily from motor temperature. They differ, of course, in detail of construction to meet space and mounting conditions. In general, they incorporate separate heaters for adequate motor protection under locked-rotor conditions. In some designs they are heated by the current which flows

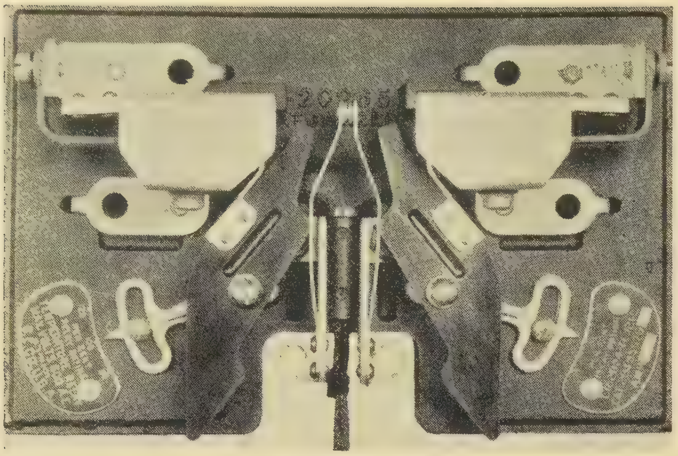


Fig. 9. Adjustable bimetal thermal overload relay (General Electric)

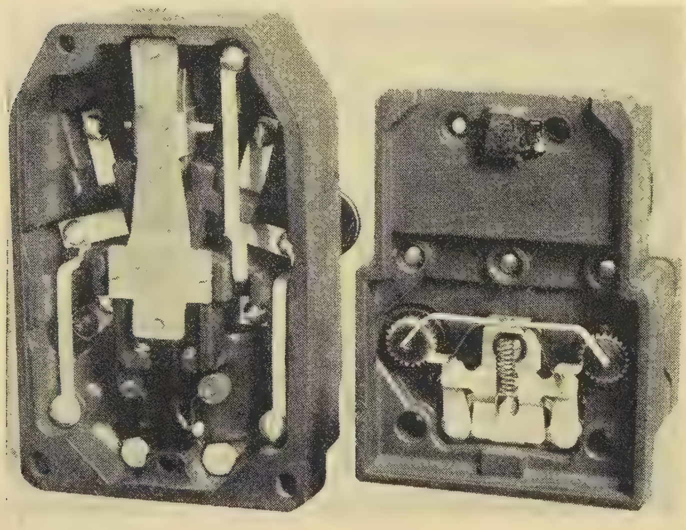


Fig. 10. Manual starters with nonadjustable solder-film thermal overload units (left, Cutler-Hammer; right, General Electric)

through the overload mechanism or the bimetal operating strip.

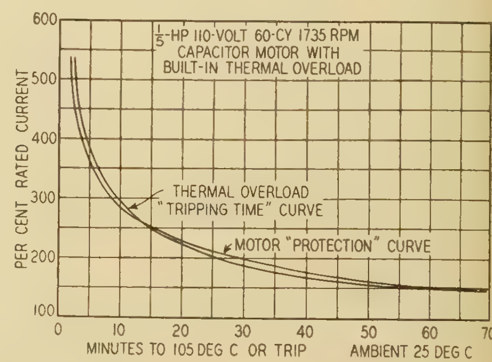
The performance of a thermal overload device built into a motor differs from that of a separately mounted overload unit. Its tripping current is obviously influenced by motor temperature. Consequently, the time characteristics of such an overload device more closely approximate those of the motor, and greater capacity is obtained for carrying short time, heavy overloads. Figure 11 shows motor "protection" and thermal overload relay "tripping time" curves for a solder-film overload relay mounted in the end bell of a capacitor-start motor.

Such motor-mounted overload devices do not, however, follow motor characteristics as closely with variations in ambient temperature. If the motor were to reach the same maximum safe temperature under all conditions, the temperature surrounding the overload would tend to remain constant and the tripping current would be constant. Obviously such conditions cannot be obtained inasmuch as the motor requires materially increased current at lower ambient temperatures for a given maximum safe motor temperature. Therefore, the motor will tend to run cooler at normal ambient temperatures if adequately protected at maximum ambient temperature by a built-in overload device.

Cycling Overload

The "cycling overload" is an automatic resetting thermal overload device. The contacts are placed in the line circuit to the motor. When it trips, the motor is de-energized. When it resets, the motor again attempts to start. This type of motor protection is only used commercially for fractional-horsepower motors. Its principal application is on motors for refrigeration. Such

Fig. 11



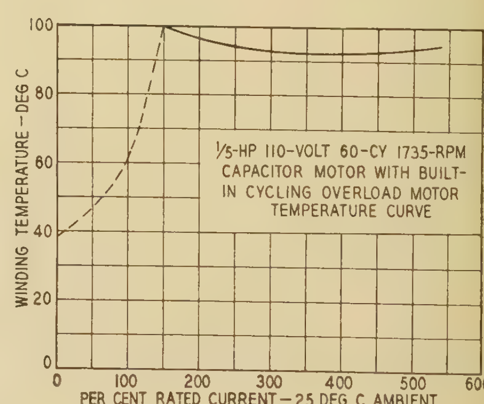


Fig. 12

motor protection is not a new development in this field although its use has recently become more widespread.

The use of "cycling overloads" for domestic refrigerators has 2 advantages over the manually reset type of overload protection. It permits the use of a smaller motor for starting a refrigerator which has been out of service in warm weather by stopping the motor periodically. This first starting, after being out of service, requires considerably more power than that required to cycle the refrigerator after it has reached normal operating temperatures. The other advantage is that it will restart the refrigerator after a shutdown due to such temporary conditions as, low voltage during a storm, which may cause the refrigerator motor to stall and the overload device to trip.

The "cycling overload" like any other can be used either as a separately mounted device or it can be built into the motor. Figure 12 shows motor temperatures for continuous cycling on overload at various heavy overloads including locked rotor conditions.

Determining Motor Protection

Motor overload protection can be determined by a comparison of the proper motor and thermal overload relay data. For industrial control applications the following considerations are important.

1. The tripping time of the thermal overload relay should be less than the time required for the motor to reach a dangerous temperature at any load. This can be determined by comparing the "tripping time" curve of the thermal overload relay with the "protection" curves of the motor. The latter should include single phase as well as polyphase operation for polyphase motors.

The thermal overload relay will have a higher rating than the full load rating of the motor for most applications. This overload capacity must be decided upon when comparing "tripping time" and "protection" curves and both considered in common terms of amperes or motor full-load current.

2. Locked-rotor protection can be determined from motor "locked-rotor data" and the "tripping time" curve of the thermal overload relay. The tripping time of the thermal overload relay selected should be less than the time for the motor windings to reach a dangerous temperature. Consideration should be given single-phase performance as well as polyphase performance of polyphase motors.

3. To obtain the best motor protection and to permit operating the motor continuously at maximum safe load, it is generally desirable to have the thermal overload relay installed where it will be subject to the same ambient temperature as the motor. When this relation exists it is an easy matter to determine motor overload protection by comparing the motor "load" curve with the "tripping current" curve of the thermal overload relay. Again this comparison can best be made on a common basis of amperes or per cent motor full-load current.

Installations which require the thermal overload relay to operate at materially different ambient temperatures than the motor should have motor "load" curve and thermal overload relay "tripping current" curves investigated for the corresponding expected ambient temperatures. Complete motor overload protection under such conditions will result in limiting motor capacity below the safe value which would be permitted if both motor and thermal overload relay were installed in the same ambient temperature.

The performance of thermal overload devices built into motors can best be determined by tests of the combined assembly. Such installations are effected by air circulation in the motor and heat conducted from the motor parts to the thermal overload device.

"Cycling overload" applications are likewise best made from actual test data of the combination motor and "cycling overload." An investigation can be made for separately mounted "cycling overload" applications, similar to that outlined for industrial control. It is essential, however, to investigate cycling conditions particularly those for locked rotor. The time the "cycling overload" contacts are closed under such conditions is very short and the motor is energized only a small percentage of the time. A necessary requirement for motor protections is that the "cycling overload" have a smaller "per cent time on" at locked rotor current than the ratio of full-load motor loss watts to locked rotor watts.

Industry is conscious of its a-c motor overload protection problem. This is indicated by the development work being done by both control and motor manufacturers. Perhaps further advancement will be made in the art in the not too distant future.

Survey of Marine Radio Progress

A paper entitled "A Survey of Marine Radio Progress, With Special Reference to R. M. S. 'Queen Mary'" by Commander F. G. Loring, W. L. McPherson, and W. H. McAllister, was read before The Institution of Electrical Engineers in London, England, on March 3, 1937. This 35-page paper, with 29 illustration and tables, gives a general survey of the field of marine radio with a view to placing on record the state of the art as of 1936. A short summary of progress during the past 5 years with particular reference to the nature and volume of traffic, the types of communication involved, and the growing use of direction-finding equipment by navigators is given. Special attention is paid to the types of radio equipment now customarily fitted in cargo vessels and in passenger vessels other than those of the "express steamer" class.

In order to give a description of the problems and how they are met on "express steamer" class of vessels, the R. M. S. "Queen Mary" is used as an example. The actual radio station of this ship and its associated power supply and antenna systems are described. The control room arrangements handle 4 independent duplex circuits which require special precautions to insure efficient multiplex working, quick change of wave length, high-speed transmission and reception, and simultaneous communication on both telephony and telegraphy with both sides of the Atlantic.

With the introduction of subscriber's ship-to-shore radiotelephone service, terminating equipment was required for ship installation. The primary function of the equipment is to prevent local interaction between radio transmitter and receiver, and in addition it may provide a "privacy" system to render speech unintelligible to unauthorized listeners.

On the "Queen Mary" service was planned to be of the same nature as that furnished on the transoceanic radiotelephone links, so that the terminating equipment is more complete than hitherto fitted in ships and includes a privacy system. Communication equipment is housed in 3 separate rooms: the power room, near the engine room of the ship, which contains 2 45-kva alternators (one a spare unit) operated from the d–c supply of the ship; the transmitting room, on the sun deck, which contains the 4 main transmitters and the power control and distribution board; and the operating room, on the sun deck and about 400 feet from the transmitting room, which contains all receivers, telephone terminal equipments, remote-control apparatus, transmitting keys, high-speed transmitting and receiving apparatus, and a complete emergency station. Thirteen antennas are required for transmitting and receiving on various frequencies and for the direction finder.

Sixty-Cycle Calibration of the 50-Centimeter Sphere Gap

By C. S. SPRAGUE
ASSOCIATE AIEE

G. GOLD
NONMEMBER AIEE

ONE OF the important functions of the Institute is to provide specifications relating to the standardization of testing equipments and methods. Since the publication of AIEE Standards No. 4, May 1928, considerable progress has been made in the extension and revision of the calibrations for the grounded sphere gap for both 60-cycle and impulse voltages. This paper presents data which should be of assistance in establishing the calibrations of ungrounded sphere gaps. In addition to these data, the paper also describes the equipment and method used in determining the crest voltage applied to the spheres and the means of determining the spacing at spark-over. Data are also presented upon the effect of ultraviolet irradiation of the spheres.

Summary

1. Ultraviolet radiation of the spheres materially improved the consistency of the sphere gap.

2. As compared with the nonirradiated gap the spark-over spacing of the irradiated gap was slightly but definitely increased over the whole range.

3. The curve of the nonirradiated gap checks the calibration as given in AIEE Standards No. 4 up to approximately 300 kv but falls below standard curve above this point.

4. The vacuum-tube type crest voltmeter used in conjunction with a capacitance potential divider was found to be very satisfactory and convenient both for calibrating the sphere gap and for everyday measurements of 60-cycle crest voltages.

General Description of Equipment and Setup

The photograph of figure 1 illustrates the spheres, resistors, leads, etc. and the manner in which they were supported. The spheres were of copper, 50 centimeters in diameter, conforming to the AIEE specifications. The shanks were of 3-inch diameter smooth brass tubing, and were 6 feet long. As will be seen from figure 1, each sphere was supported at the shank by 2 pairs of ropes, each pair arranged in the form of a *V* and fastened to the shank in such a manner as to leave the shank free of loose rope ends, collars, etc. At the upper ends of the *V* each rope was passed over a small pulley fastened to the wooden frame. The axis of the gap was 12 feet above the concrete floor of the laboratory. With the exception of the shanks, supporting ropes, Uviarc lamp, floor, etc., no other bodies were within 16 feet of the spheres. Individual adjustment of the 8 supporting ropes allowed careful aligning of the gap.

A total series resistance of 2 ohms per volt (effective value) was enclosed in the shields at the ends of the shanks, half of the resistance in the lead to each sphere. The leads from the resistances to the transformer terminals were composed of 3- and 4-inch diameter galvanized iron pipe.

It will be seen that some considerable precautions were taken to eliminate corona formation. In this respect the arrangement was satisfactory as corona became noticeable only at voltages greater than the accepted accurate range of the gap.

The gap spacing was adjusted by pulling back either or both spheres. It may be noted here that the upper ends of the ropes supporting the spheres were so located that there was always tension upon the ropes used to pull back the spheres, thus eliminating all slack or tendency of the spheres to swing. One sphere was provided with a relatively coarse adjustment and the other with a closely controlled continuously variable adjustment. This allowed each sphere to be pulled back approximately the same amount so that the sphere axes would be in line at spark-over.

The sphere spacing at spark-over was measured by means of a telescope, set with its axis perpendicular to the axis of the sphere gap and arranged to slide on carefully aligned ways in a direction parallel to the axis of the sphere gap. A white background shown in figure 1 facilitated accurate setting of the vertical cross hair on the sphere surfaces. The spacings were determined from the readings of a centimeter scale, fixed in position relative to the telescope base. Repeated checks of a given spacing indicated that the error of setting the telescope cross hairs and reading the scale was less than 0.3 millimeter.

Variable voltage for the spheres (up to 600 kv effective center grounded) was provided by 2 135-kva 300-kv (effective) transformers having their primary windings supplied from a tap-changing regulating transformer. Tertiary windings in the transformers were used only to provide a check upon the regulator settings. Each transformer was equipped with a condenser-type high-voltage bushing which was used as the high-voltage condenser of a capacitance potential divider. The capacitance of each bushing was carefully determined over the entire voltage range.

The crest voltage applied to the spheres was measured by means of a vacuum-tube crest voltmeter used in conjunction with the capacitance voltage divider. This crest voltmeter, primarily developed for use in this calibration work, has proved itself to be a reliable and consistent instrument for day-to-day measurement of 60-cycle crest voltages. With conservative operation of the vacuum tubes and other parts, it appears that the instrument re-

A paper recommended for publication by the AIEE committee on instruments and measurements. Manuscript received March 12, 1937; released for publication March 31, 1937.

C. S. SPRAGUE is a research assistant in the engineering experiment station of Purdue University, Lafayette, Ind. G. GOLD is employed by Porcelain Products, Inc., Parkersburg, W. Va.

The writers express their appreciation to Doctor C. F. Harding, head of the school of electrical engineering, Purdue University, for his interest and encouragement in this work.

tains its calibration for an indefinite period. Some other advantageous features of the vacuum-tube crest voltmeter are:

1. Crest voltage readings are obtained independently of wave shape.

2. The crest voltage reading is proportional to the average crest of a number of successive cycles and is unaffected by occasional surges or high-frequency oscillations in the voltage supply.

3. It does not load the capacitance voltage divider, or otherwise affect its ratio.

4. Provides a continuous indication of crest voltage and responds quickly to changes in the crest voltage.

5. Crest voltage readings are to a high degree independent of the supply voltage to the instrument. This is because the operation depends not upon the absolute currents in the vacuum tubes, but rather upon the differential current which is caused to be a function of the applied crest voltage.

The obvious disadvantage of the instrument is that a high-voltage capacitor of known and constant capacitance is required for the potential divider.

The source of ultraviolet radiation was a 220-volt Uviarc operating at approximately 4 amperes and with a drop of 170 volts across the tube. This source was placed 12 feet from the axis of the gap and at the same height above floor level.

Method of Calibration

The general procedure in determining the relation between voltage and spark-over distance is to assume one of the variables as independent, and to adjust the second until spark-over occurs. The choice usually depends upon the manner and convenience with which the respective factors may be uniformly varied or held constant as the case may be. Thus the spacing may be fixed and the voltage increased to spark-over or the voltage may be set at some desired value and the spacing reduced. The latter method was chosen in this case, since, with the voltage controlled by a tap-changing regulating transformer, this latter method eliminated the possibility of surges or oscillations in the voltage due to sparking at regulator contacts.

In determining the spark-over distance corresponding to a given voltage each sphere was pulled back an equal amount to provide a spacing approximately correct for the voltage used. The sphere with fine adjustment was then pulled back still farther and the voltage applied and set to the desired value. The spacing was then gradually and uniformly reduced until spark-over occurred. The spheres were held at this spacing and the spacing determined by means of the telescope. In this way a large number (10–20) of readings, both with and without ultraviolet irradiation, were taken for each voltage with an average interval of about 3 minutes between readings.

In the first calibration 12 points were taken up to spacings approximately equal to the sphere diameter. A second calibration was then made using 11 intermediate points and later several of the original points were rechecked. The fact that a smooth curve can be drawn through all the points should be reasonable proof of the accuracy of the work and of the consistency of the setup.

Barometer, temperature, and humidity readings were obtained frequently and the final results corrected to a relative air density of unity.

It was quite frequently noticed, when beginning a series of readings after an interval during which the gap had not been sparked over, that the first 2 or 3 spacings obtained were higher than subsequent spacings, in other words, the gap seemed to break down easier. Accordingly from 3 to 6 "clean up" spark-overs were allowed before actually taking data.

With due care, the spacing of the spheres could be reduced very gradually and uniformly with no tendency toward mechanical oscillation or other undesirable motion of the spheres. During this operation the crest voltmeter reading was observed up to the instant of spark-over. Thus, any slight and gradual changes of voltage would be indicated. In general, however, neither the tertiary voltmeter nor the crest voltmeter indicates the presence of short-time surges or high-frequency oscillations which may exist in the power supply system due to external causes, such as switching operations or suddenly changing loads. Occasional erratic readings were obtained and these were

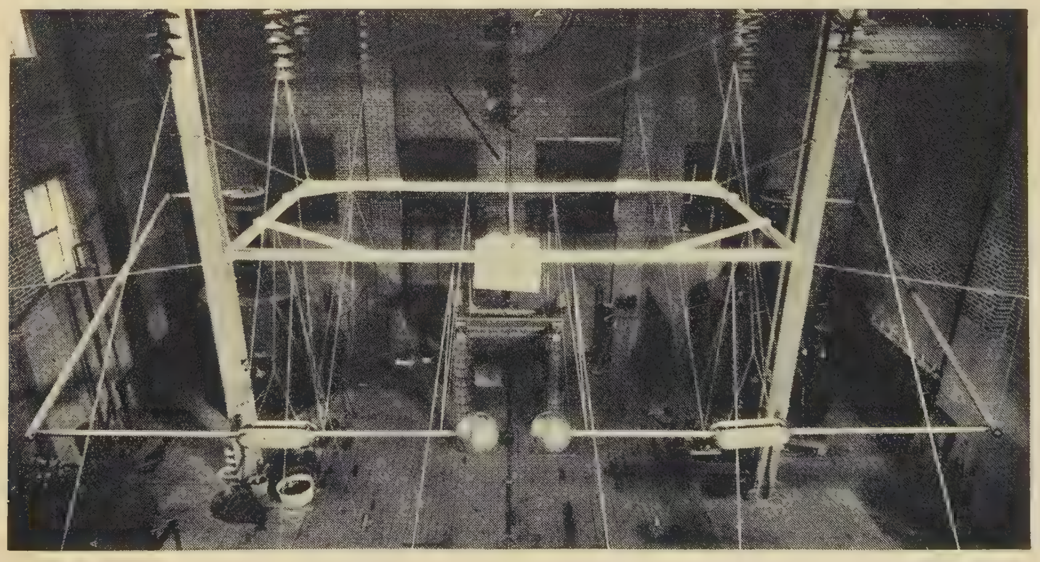


Fig. 1. Photograph showing arrangement of 50-centimeter ungrounded sphere gap

attributed to the above factors and were not used in averaging the results.

Calibration Data

Table I presents the calibration data for the actual test points and is presented principally to illustrate the effect of ultraviolet radiation in decreasing the scattering of individual readings and increasing the spacing.

Table II provides the final calibration data, the values being taken from a smooth curve drawn through the points of table I. Data from the calibration as given in AIEE Standards No. 4 is also provided for comparison.

Accuracy of Results

As stated before the telescope settings for a given spacing could be repeatedly checked within 0.3 millimeter or within 0.15 millimeter of the average of a large number of readings. There was, however, a second possible error in the measurement of spacing due to a possible change in the angular position of the telescope as it was moved laterally along the parallel ways. Such a change could be caused either by a localized high spot, or by a general and gradual curvature or bowing of the ways. In the former case the high spot might be permanent in which case its effect would be averaged out in drawing the final smooth curve, or the high spot might be caused by loose foreign matter so that its effect would be minimized in averaging a large number of readings for a given point. In the case of a gradual bowing of the ways the error would tend to be of constant percentage. These factors were duly taken into account and considerable care was taken to assure that the motion of the telescope was as nearly truly parallel as possible. It is believed that the maximum possible error is not greater than one millimeter and that the probable error, in consideration of the averaging processes mentioned above, is of the order of 0.5 millimeter.

Table I—Test Data for 50-Centimeter Ungrounded Sphere Gaps Corrected to Standard Atmospheric Conditions (Delta = 1)

Voltage, Kilovolts Crest	Average Spacing, Millimeters		Maximum Deviation From Average Spacing in Per Cent			
	Non-irradiated	Irradiated	Nonirradiated +	Nonirradiated −	Irradiated +	Irradiated −
72.2	25.1	25.1	2.7	0.4	0.4	0.0
106.2	37.4	38.2	1.6	1.0	0.1	0.4
125.6	44.9	45.8	0.4	0.7	0.9	0.4
181.5	66.1	67.0	0.8	0.3	0.7	0.7
212.6	78.3	79.5	0.5	1.1	0.6	0.6
256	95.2	96.6	1.4	1.5	0.3	0.2
282	107.8	109.8	0.9	0.8	0.6	0.1
325	126.0	127.5	0.8	0.1	0.2	0.1
352	138.7	140.8	0.6	0.4	0.1	0.1
364	144.8	146.0	1.5	1.0	0.7	0.6
397	161.5	164.0	0.7	0.4	0.1	0.1
403	164.1	167.1	2.2	1.8	0.8	0.6
430	181.6	183.0	0.5	0.3	0.5	0.4
464	200.6	204.0	0.3	0.3	0.2	0.2
498	218.4	223.0	0.7	0.9	0.5	0.1
536	244.0	244.7	0.4	0.6	0.4	0.1
570	265.9	266.6	1.4	0.8	0.2	0.2
613	292.5	293.5	0.4	0.3	0.6	0.4
637	308.8	311.9	1.1	1.0	0.1	0.2
675	337.5	336.6	1.0	1.2	1.0	0.4
719	366.1	370.2	0.7	0.6	0.8	0.3
736	381.9	383.7	0.4	0.6	0.2	0.3
790	428.4	431.3	0.8	0.6	0.4	0.5
802	445.0	443.1	0.9	0.9	0.2	0.3

The accuracy of measurement of the crest voltage depended upon the accuracy of the calibration and of the reading of the crest voltmeter, and on the accuracy of the determination of the ratio of the capacitance voltage divider. The crest voltmeter as mentioned before is not affected by surges and reads the average crest value of a number of cycles. Hence any individual voltage reading might be in error by an undetermined amount depending on the presence and magnitude of any high-frequency surges in the distribution system. Such disturbances were relatively infrequent and it is felt that their ultimate effect was negligible.

Table II—Calibration Data for 50-Centimeter Ungrounded Spheres (Delta = 1)

Sphere-Gap Spacing, Centimeters	Spark-Over Voltage, Kilovolts Crest		
	Nonirradiated	Irradiated	Standards No. 4
5.0	139	137	139
7.5	204	201	204
10.0	266	263	265
12.5	322	318	326
15.0	374	369	381
17.5	422	416	431
20.0	465	460	475
22.5	507	502	516
25.0	545	542	557
30.0	624	621	632
35.0	695	692	702
40.0	764	761	—
45.0	808	806	—
50.0	850	847	—

The accuracy of calibration and of reading the crest voltmeter were each within $1/4$ of 1 per cent. The ratio of the voltage divider was determined by individual measurements of the capacitance of the condenser-type bushing over the entire voltage range and of the capacitance of the series low-voltage condenser. Except for the extreme upper end of the curve where corona became noticeable, it is believed that this ratio was determined within 1 per cent. Thus the maximum possible error in determining the crest voltages was of the order of $1^1/_2$ per cent with an estimated probable error of the order of one per cent.

In consideration of the probable errors in determining the spacing and the crest voltage, and of the averaging processes previously mentioned, it may be stated that the final calibration data of table II are accurate to a probable one per cent.

Conclusions

Ultraviolet irradiation of spheres produces a distinct lowering of the spark-over voltage for a given spacing and

(*Concluded on page 600*)

Probable Outages of Shielded Transmission Lines

By S. K. WALDORF
MEMBER AIEE

I. Synopsis

Based on the observed phenomenon that flashover of transmission-line towers provided with 2 overhead ground wires occurs only when the product of tower-footing resistance and tower surge current exceeds the insulation strength, the probable outages that will occur on a line can be obtained by a simple method. Only those factors enter into the calculations which have become generally accepted quantitatively.

Computations have been made for 3 transmission lines and the results compared with operating records. The agreement has been very good.

II. Introduction

SINCE the introduction of the surge-crest ammeter and complementary magnetic links, data have been accumulating which indicate that flashover due to a lightning stroke to a tower occurs only when the product of tower surge current and tower-footing resistance exceeds the insulation strength of the line.[1] If an insulated line conductor is struck, flashover almost invariably occurs. Hence, for a transmission line to be highly resistant to lightning, overhead ground wires are needed to shield the line conductors from direct strokes, and tower footing resistances must be co-ordinated with line insulation.

In order for estimates of line performance to be made in any particular case, several factors must be known quantitatively. These factors are:

1. Degree of shielding of line conductors provided by the overhead ground wires
2. Line insulation strength
3. Tower-footing resistance of every tower of the line
4. Tower surge currents caused by lightning

III. Evaluation of Factors

At the present time, the art has advanced sufficiently that overhead ground wires can be so placed as to be highly effective in shielding line conductors from lightning.[1,2,3] For evaluating the efficacy of any given arrangement of ground wires and line conductors, scale models can be tested in the laboratory, utilizing an impulse generator.

The second factor to be evaluated is insulation strength, which is much affected by the rapidity of rise and fall of the applied voltage. There is evidence available, though not conclusive, that most lightning strokes cause tower voltages which do not attain their maxima for several microseconds.[5,6,7,8] These data indicate that the impulse strength of line insulation can be taken without serious error as that obtained with the standard $1^1/_2$ x 40 microsecond wave rather than with the 1 x 5 microsecond one.[9] Due to capacitive-coupling effects between overhead ground wires and line conductors, the strength of insulation installed on a transmission line is greater than that of the insulator strings alone.[10]

The values of ground resistance used for the calculations are those obtained by conventional methods of measurement. The resistance of a tower footing should include only that of the foundation and that of any auxiliary grounding connected to the tower which is in the immediate neighborhood of the tower. The overhead ground wires should be insulated from the tower during measurement.

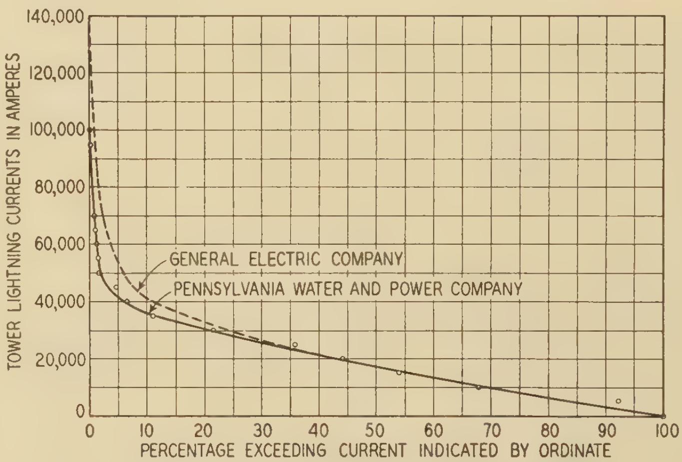


Fig. 1. Distribution of lightning currents in towers believed struck by lightning

Observations made with the surge-crest ammeter have shown that tower currents of various intensities produced by lightning occur in a fairly regular manner. The distribution of intensities of current in towers struck by lightning is shown in figure 1. The General Electric Company[1] and Pennsylvania Water and Power Company curves are in relatively close agreement. The tower currents included in the former curve were caused by 358 separate strokes. The data included in the Pennsylvania Water and Power Company curve were obtained during 1934, 1935, and 1936 from 419 strokes. From these curves, the fourth factor needed for calculation can be evaluated.

A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted January 13, 1937; released for publication March 6, 1937.

S. K. WALDORF is test engineer for the Pennsylvania Water & Power Company, Baltimore, Md.

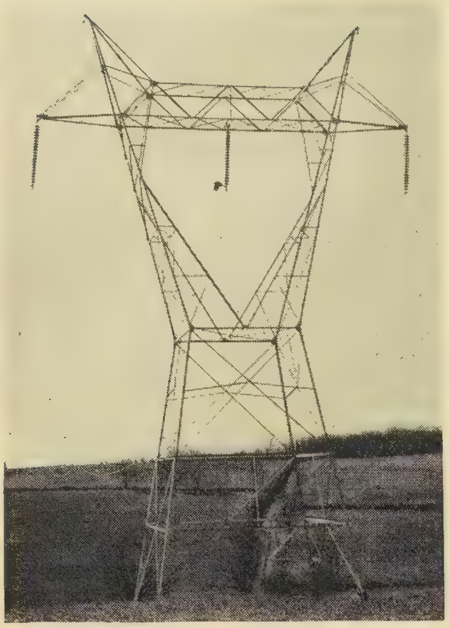


Fig. 2. Single circuit, horizontal configuration, suspension tower of the Safe Harbor-Westport-Takoma 230-kv line

Two overhead ground wires are installed

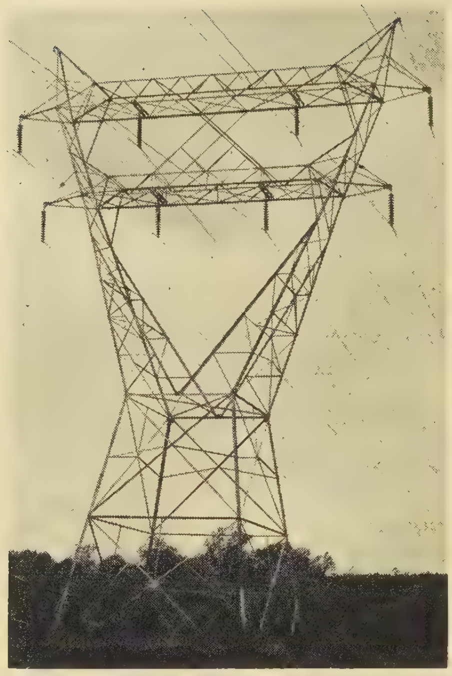


Fig. 3. Four-circuit, single-phase suspension tower of the Safe Harbor-Perryville 132-kv line

Two overhead ground wires are installed

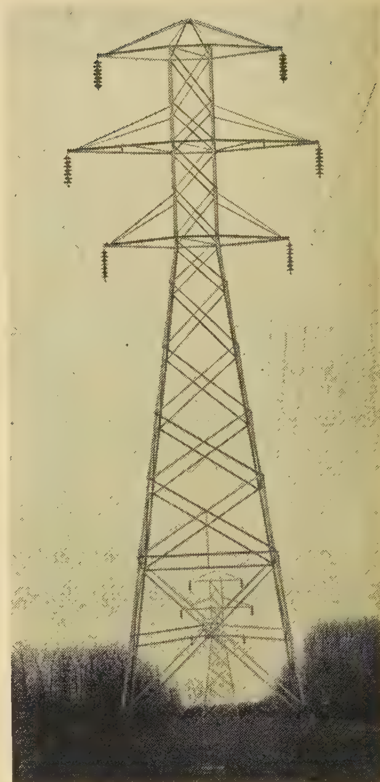


Fig. 4. Tower of Holtwood-York 69-kv line before installation of lightning protection

IV. Basis of Probability Calculations

When calculating the number of outages which will probably occur on a transmission line by the method presented here, there are some assumptions made which operating experience has indicated are reasonable. These are:

1. Two overhead ground wires can and will be so provided that any strokes terminating on the line will contact only a tower or overhead ground wire. If the shielding provided is imperfect, strokes to line conductors will nullify any estimates to some extent.

2. Ohmic ground resistance as determined by conventional methods in most cases approximates the footing impedance effective during lightning discharges to a line structure.

3. Flashover occurs on a shielded line only when the product of tower footing resistance and tower crest current exceeds the insulation strength of the line at the struck tower.

4. The insulation strength of the line referred to in 3 is that determined by the conventional $1^1/_2$ x 40 microsecond wave with electrostatic coupling effects taken into account.

5. Clearance between ground wires and line conductors at midspan is such that the flashover value there is co-ordinated with that at towers.

6. Over a period of time, and with a large number of instances, lightning phenomena and related data are amenable to statistical methods.

7. All sections of a transmission line are equally subject to lightning. If such should not be the case, the line may be divided into sections which meet this requirement.

Table I—Probability of Outage Data and Calculations Safe Harbor-Westport-Takoma 230-Kv Line

Ranges of Tower-Footing Resistance	Towers in Range Number	Towers in Range Per Cent	Maximum Safe Tower Current for Towers in Range	Percentage of Tower Currents in Excess of Safe Values	Probability of Flashover
0– 5	49	10.3	495,000	0	0
6–10	141	29.6	247,500	0	0
11–15	126	26.4	165,000	0	0
16–20	136	28.5	124,000	0.2	0.00057
21–25	13	2.7	99,000	0.7	0.00019
26–30	5	1.1	83,000	1.5	0.00017
31–35	3	0.6	71,000	2.4	0.00014
36–40	2	0.4	62,000	3.0	0.00012
41–45	1	0.2	55,000	4.5	0.00009
46–50	0	0.0	50,000	5.5	0
51–55	1	0.2	45,000	7.5	0.00015
Totals	477	100.0			0.00143

Flashover voltage of insulator strings (20 $5\ ^1/_4$-inch units) with $1^1/_2$ x 40 microsecond wave = 1610 kv
Coupling factor for 2 overhead ground wires = 0.35
Line Data: (See figure 2)

To illustrate the underlying probability theory, a transmission line of a towers will be considered. Over a period of time, there is one chance in a that any one particular tower will be struck by a particular stroke of lightning. If there should be more than one stroke, the chances are increased in direct proportion.

As flashover is not caused by every stroke terminating on a tower, the critical intensity of the lightning current for a given tower can be found from the following relation:

$$\text{Maximum safe tower current} = \frac{\text{Flashover voltage of insulator strings}}{\text{(1-Coupling factor)} \times \text{Tower footing resistance}}$$

From figure 1, suppose that b *per cent* of the number of strokes c to the line per year are found to cause tower

currents which exceed the critical value calculated for the particular tower considered. Then, the probable number of flashovers which will be experienced by this particular tower is:

$$\frac{1}{a} \times \frac{b}{100} \times c \text{ flashovers per year}$$

If the probable flashovers per year are found for every tower of the line, and then summarized, the probable flashovers per year for the entire line will be obtained.

Table II—Grounding Data; Safe Harbor-Perryville 132-Kv Line and Holtwood-York 69-Kv Line

Ranges of Tower Footing Resistance	Towers in Range: Safe Harbor-Perryville Number	Safe Harbor-Perryville Per Cent	Holtwood-York Number	Holtwood-York Per Cent
0– 5	24	13.4	36	20.4
6–10	70	39.1	87	49.1
11–15	48	26.8	41	23.2
16–20	34	19.0	13	7.3
21–25	2	1.1	0	0
26–30	1	0.6	0	0
Totals	179	100.0	177	100.0

As shown later, the calculation need not be made for each tower of a line, but only for groups arranged according to tower footing resistances.

V. Typical Application of Method

The probable outages that will be experienced on the Safe Harbor-Westport-Takoma 230-kv line[11,12] have been calculated by the method just outlined. The procedure followed will be given in detail.

Sample Calculation: (See table I)

$$\text{Maximum safe tower potential} = \frac{1610}{(1 - 0.35)} = \frac{1610}{0.65} = 2{,}475 \text{ kv}$$

$$\text{Maximum safe current for towers of 21–25 ohm range} = \frac{2475}{25} = 99{,}000 \text{ amperes}$$

From the upper curve of figure 1, approximately 0.7 per cent of measured tower currents exceed 99,000 amperes. Also, from table I it is found that 2.7 per cent of the towers comprising the line have footing resistances in the 21–25-ohm range.

Therefore, probability of outage due to towers in 21–25-ohm range = 0.027 × 0.007 = 0.00019. The probability for the entire line is the sum of those for the towers in the individual ranges.

Hence, probability of outage for entire line = 0.00143. Lightning current observations have indicated 115 strokes to this line in 1935 and 108 in 1936, or an average of 112 strokes to the line per year.

Probable outages per year = 112 × 0.00143 = 0.16. This is equivalent to one probable outage in 6 or 7 years.

The method can be used for estimating the performance of projected transmission lines or of existing lines for which improvements are comtemplated. This was done for the Holtwood-York line described in section VI before improvements in lightning protection were installed, and the result obtained was not greatly different from that reported in section VI. The principal difficulty in applying the calculation in such cases is estimating the tower footing resistances which will be obtained. The best approach to the solution of this difficulty is the analysis of data obtained on lines situated in territory comparable to that of the line considered.

Table III—General Line Data; Safe Harbor-Perryville 132-Kv Line and Holtwood-York 69-Kv Line

	Safe Harbor-Perryville	Holtwood-York
Length (miles)	31.5	22.8
Insulator size	$5\frac{1}{4}$ inches	$4\frac{3}{4}$ inches
Insulators in suspension	12	8
$1\frac{1}{2}$ x 40 microsecond flashover	1,025 kv	675 kv
Average strokes to line per year	48	31

VI. Calculated Performance and Operating Experience

The test of any method of estimating the probable performance of transmission lines during lightning seasons must necessarily be the operating records. At this time it is possible to give such a comparison of estimated and actual performance for three transmission lines over various periods of time. Although the operating period is relatively short in each case for any conclusions to be drawn, the results thus far are believed to be significant.

Fig. 5. Double-circuit, vertical configuration, suspension tower of the Holtwood-York 69-kv line

Present appearance, with 2 overhead ground wires installed

As shown in section V, calculations indicate that over a period of time there should be about one outage of the Safe Harbor-Westport-Takoma 230-kv line every 6 or 7 years. This line has actually been in service for only 5 years, during which time one outage occurred.

In figure 3, is shown a tower of the Safe Harbor-Perryville 132-kv line which supplies energy to the electrified section of the Pennsylvania Railroad between Washington and Perryville. This line has been in operation through the lightning seasons of 1935 and 1936 without any outage occurring, even though the surge crest ammeter links indicated 27 strokes to the line in 1935, and 69 in 1936. In tables II and III are given data for this line. Calculations indicate that there will probably be one outage every 4 years over a period of years.

Table IV—Actual and Probable Outages of 3 Transmission Lines

Line	Years of Operation	Lightning Outages per Year	
		Actual	Probable
Safe Harbor-Westport-Takoma	5	0.20	0.16
Safe Harbor-Perryville	2	0	0.27
Holtwood-York (improved)	$1^1/_4$	0	0.38

The Holtwood-York 69-kv line until 1935 operated without any overhead ground wire or auxiliary grounding. The appearance of the line at that time is shown in figure 4. By August 1935, 2 continuous counterpoises[13] and 2 overhead ground wires were installed which eliminated all flashovers in the subsequent period through 1936 (about $1^1/_4$ lightning seasons). The present appearance of the line is shown in figure 5. Line data are given in tables II and III. Calculation shows that one outage in about 3 years can be expected on this line.

VII. Summary

Data have been accumulating which permit the computation by a simple method of the probable lightning outages of a transmission line protected by overhead ground wires. Only those factors enter into the calculations which have become generally accepted quantitatively.

The results of computation and the operating record of 3 transmission lines are compared in table IV.

The agreement of results of computation and experience, and the simplicity of the method warrant its use for estimating the probable lightning performance of shielded transmission lines over a period of years.

References

1. Lightning Investigation on Transmission Lines—VI, C. M. Foust and W. W. Lewis. Electrical Engineering, volume 56, January 1937, pages 101–6, 189.

2. Lightning Discharges and Line Protective Measures, R. N. Conwell and C. L. Fortescue. AIEE Transactions, September 1931, pages 1090–1100.

3. Lightning Investigation on Transmission Lines—V, C. M. Foust and W. W. Lewis. Electrical Engineering, volume 54, September 1935, pages 934–41.

4. Lightning, G. C. Simpson. *Journal* of the Institution of Electrical Engineers, volume 67, 1929, pages 1269–82.

5. Progressive Lightning, H. Collens and B. F. J. Schonland. *Proceedings*, Royal Society of London, February 1934, pages 654–74.

6. On the Nature of Lightning Discharges, H. Norinder. *Journal* of the Franklin Institute, volume 218, number 6, pages 717–38.

7. Lightning Investigation on Transmission Lines—IV, C. M. Foust and W. W. Lewis. Electrical Engineering, volume 53, August 1934, pages 1180–86.

8. 4500-Kv Surge Recorded in Arkansas, J. J. Torok. *Electrical World*, September 6, 1930, page 442.

9. Flashover Voltages of Insulators and Gaps, AIEE Committee Report. Electrical Engineering, volume 53, June 1934, pages 882–6.

10. Discussion, L. V. Bewley. Electrical Engineering, volume 55, August 1936, page 921.

11. Safe Harbor-Westport 230-Kv Transmission Line, E. Hansson. Electrical Engineering, volume 51, December 1932, pages 834–8.

12. Lightning Performance of 220-Kv Lines, AIEE Committee Report. Electrical Engineering, volume 53, November 1934, pages 1443–7.

13. Practical Applications of the Counterpoise, E. Hansson. *Electric Journal*, volume 33, June 1936, pages 281–5.

Calibration of the 50-Centimeter Sphere Gap

(*Continued from page 596*)

has a decidedly beneficial effect in reducing the scattering of individual readings.

If ultraviolet light is to be used with sphere gaps, the gap calibration should be determined under the irradiated condition. Although no tests were made in this work using varying intensities of irradiation, it seems probable that the calibration and use of the irradiated sphere gap should be, for the greatest accuracy, specified for a particular range of radiation intensities.

The results of this investigation indicate that, for non-irradiated spheres, the previous calibration gives crest voltages which, in the range above 250 kv, are from 2 to 12 kv too high. For the irradiated spheres the previous calibration appears to be in error by a still greater amount, and gives voltages which are too high over the entire range.

Bibliography

1. Measurement of Test Voltage in Dielectric Tests, AIEE Standard No. 4, May 1928.

2. Calibration of the Sphere Gap, J. R. Meador. AIEE Transactions, volume 53, June 1934, page 942.

3. Impulse Calibration of Sphere Gaps, P. L. Bellaschi and P. H. McAuley. *Electric Journal*, June 1934.

4. The Sparkless Sphere Gap Voltmeter, R. W. Sorensen, J. E. Hobson, S. Ramo. AIEE Transactions, volume 54, June 1935, page 651.

5. The Sparkless Sphere Gap Voltmeter—II, R. W. Sorensen, S. Ramo. AIEE Transactions, volume 55, May 1936, page 444.

6. Effect of Ultra-Violet on Breakdown Voltage, G. L. Nord. AIEE Transactions, volume 54, September 1935, page 955.

7. Spark Lag of the Sphere Gap, S. Tilles. AIEE Transactions, volume 54, August 1935, page 868.

8. Revised Sphere-Gap Spark-Over Voltages, Report by Committee on Instruments and Measurements. AIEE Transactions, volume 55, July 1936, page 783.

Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

On this and the following 33 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the sessions on electrophysics, electrical machinery, induction machinery, power transmission, and tensor analysis at the 1937 AIEE winter convention, New York, N. Y., January 25–29. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at any AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y.

Expansion Theorems for Ladder Networks

Discussion and authors' closure of a paper by Michel G. Malti and S. E. Warschawski published in the January 1937 issue, pages 153–8 and 152, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1937.

J. J. Smith (General Electric Company, Schenectady, N. Y.): This paper gives a systematic method of finding the currents and voltages in ladder networks under steady-state conditions. The usual method for such problems has been to find a general solution containing unknown constants and then evaluate these by satisfying certain boundary conditions. While this is readily done for the simpler types of networks, the determination of these constants corresponding to a given physical problem is often a difficult one for more complicated networks. For such cases the solutions given in equations 24*a* and 24*b* supply a direct method of obtaining the result.

It would appear desirable to make it clear at the outset of the paper that these solutions apply only to steady-state conditions since this is not apparent now until one has followed through the work. I wonder if the authors have made any further studies with regard to the extension of their solution to transient conditions.

The problem solved by the authors is of the type Heaviside refers to as "given the cause, find the effect" since they assume a certain network and derive its admittance at a given frequency. In his paper last year Malti showed how the method he followed was also directly applicable to the inverse of the Heaviside expansion theorem since such problems do not require the solution of the complex integral corresponding to equation 6. The inverse problem of the type "given the effect, find the cause" is also of interest since in this case we are given the admittance we desire at various frequencies and wish to find a physical network which will have such characteristics. I should like to inquire if the authors have looked into the possibilities of applying their method to this type of problem.

M. G. Malti: Smith raised 2 important questions which I shall answer separately.

a. We are now engaged in preparing a paper covering the extension of this work to the transient state. We hope to publish this paper at some future date.

b. The inverse problem (given the cause, required the effect) is extremely involved. We hope to undertake this problem after we have worked out some of the comparatively more simple cases.

Abrasion—A Factor in Electrical Brush Wear

Discussion and author's closure of a paper by V. P. Hessler published in the January 1937 issue, pages 8–12 and 16, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 28, 1937.

M. S. Coover (Iowa State College, Ames): The research investigations on electrical brush wear that are being conducted under the direction of Hessler have served to bring to light some significant fundamental information on the subject. Anyone even superficially familiar with the phenomena of sliding electrical contacts is aware of the many variables that are not only simultaneously present in the normal operating cycles of machines from time to time, but that they are probably difficult to separate and evaluate positively in a research of any kind. Only by eliminating as many of the variables as possible and attempting to control those elements that the investigator chooses to retain can anything like dependable data be procured. The information submitted indicates that Hessler has a good understanding of the problems involved and that he has made a logical approach to them.

The photomicrographs of ring surfaces show a striking contrast between the paths produced by graphite anode and graphite cathode brushes. It seems clear that these photomicrographs give rather convincing evidence that the more rapid wear of the graphite cathode brush is produced by a ring surface condition most likely attributable to the ionization of the ring material.

The test data indicate that brush wear is caused largely by abrasion. It is interesting to discover from the information in figure 11 that the trailing metallic brush without current actually wore more rapidly than the leading metallic brush did with current. This is quite the opposite from the experience with graphite brushes. Since the author has so advantageously made use of photomicrographs to explain at least in part the action of wear in the case of carbon or graphite brushes, it suggests that possibly the same procedure might be employed for metallic brushes. Hessler does not present such photomicrographs in his paper, nor does he make reference to them. Perhaps he intends to bring out this point later.

The writer believes that the test data plotted in figure 8 and figure 9 give some quantitative idea of the breakdown of total wear into its principal components, namely, mechanical brush wear, and electrical brush wear, although no information has been included on the current densities used. It would be instructive to make comparison of these data with observations using zero current on all four brushes, other conditions remaining the same.

It is hoped that this important study can be carried further. Certainly, the new information justifies it. A better understanding of the phenomena that take place with moving electrical contacts would be of inestimable value to both designer and operator.

R. M. Baker (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Hessler has shown in a very interesting manner the large effect of abrasion on brush wear and an extension of this investigation to include operation with different gases, different brush grades and different ring material should not only help a great deal in explaining the whole process of brush wear but should also be of great value in assisting the design engineer in the choice of brushes for various applications.

It has been generally realized that the smoothness of the brush track affects brush wear, for brushes often wear much more rapidly just after the ring surfaces have

been freshly turned or stoned than later, after the rings have become polished in operation. It has not been realized generally, however, that abrasiveness could be produced in a brush track by current-carrying brushes, so that a currentless brush running in this same track would wear almost as rapidly as the brushes which carry current.

There is a seeming contradication to the findings of this paper which will be described. If a number of brushes operate in parallel on a slip ring and one of these brushes voluntarily drops its current, this brush simultaneously ceases to wear. This condition is probably brought about either by some inhomogeneity in the brush or more likely by some foreign material being picked up from the ring surface. This not only would cause the brush to drop its current but would also cause it to stop wearing. Thus one might reconcile the experience with brushes operating in parallel and having poor current division with the results of Hessler's paper.

The writer must raise a question regarding conclusion 2 of this paper. A great deal of testing experience has shown the polarity effect to be in agreement with what the author finds for carbon brushes, but opposed to what he finds for metal graphite brushes. Using his nomenclature, it is always the cathode brushes which have been found by the writer to wear most rapidly. This polarity also shows many times as much ring wear as the other polarity. The discrepency may be due to the high absolute humidity maintained by Hessler in his experiments. The moisture content (14 grains per cubic foot) is about double what one finds on the average warm summer day. The high ambient temperature may also have some effect but the ring temperature probably does not rise much above the ambient due to the small electrical and mechanical losses in the contacts. The high humidity may also account in part for the large difference in brush wear at the two polarities when the brushes are not tracking. Some of the author's own data (reference 2 in paper) indicates this fact.

M. S. May (Speer Carbon Company, Saint Marys, Pa.): Hessler is to be congratulated on his article for the large number of readings which he has apparently made and for the new ideas brought out relative to brush wear. It was formerly thought that some mysterious "electrolytic action" caused the increased brush wear when current was flowing as compared with that under no-load conditions. Hessler has shown that this difference is due to some roughening of the commutator by current with a resulting abrasion of the brush material. It is unfortunate, however, that the test could not have been of greater duration between individual readings as 24 hours is a very short period on which to base results of brush wear.

One point brought out by Hessler was of particular interest to me. In his present paper as well as his earlier one presented a year ago, he shows that the anode brush wears faster than the cathode in case of metal grades and that the cathode wears faster than the anode with the electrographite or carbon grades. This condition prevails whether the anode and cathode brushes run on individual tracks or in the same tracks. To my knowledge, there is no satisfactory explanation of this condition. It appears possible that the metal may be carried with the current to a degree sufficient to reverse the condition that prevails with the non-metal grade. This would be going back to the electrolytic theory and I would appreciate Hessler's comments.

Hessler's statement that brush wear is due primarily to abrasion is borne out by the following data tabulated from his article and indicating the brush wear is least in the grades having the maximum amount of electrical energy dissipated at the brush surfaces.

Table I

Grade	Type	At 100 Amperes Per Square Inch: Wear per 1,000 Hours	Watts at Surface
A	Electrographite	10	112
B	Electrographite	10	100
C	Carbon-graphite	16	82
D	Carbon-graphite	16	75
E	Metal-graphite	38	11
F	Metal-graphite	44	16
G	Metal-graphite	38	12

But if we assume that the abrasion is due to roughening of the ring by the current, we still have to explain why the roughening and brush wear are in inverse ratio to the wattage dissipated and bear no relation to the amperage carried.

Tests conducted over long periods on slip rings using a-c current and brushes of standard rotary-converter size indicate that other factors are involved than those discussed by Hessler. For example, a hard, heavy metal brush may wear the ring considerably more but show a lower rate of brush wear than another metal grade run under identical conditions. In this case, the brush which runs on the rougher ring shows the lower rate of wear, apparently due to properties of the brush itself.

Hessler's comments on the use of metal and nonmetal brushes on the same ring, call to mind the troubles encountered occasionally in winter on rotaries and attributed to high friction resulting from low humidity. These manifest themselves in very rapid brush wear. We have had some success in such conditions by using one pure graphite brush on each ring to supply lubricant to the metal brushes which carry the load.

There is one point that I believe should be brought out in considering Hessler's reports. The abrasion action mentioned by him as causing brush wear is not to be confused with the abrasive action discussed in brush catalogs and by brush salesmen. This latter is a characteristic of the brush itself due to the presence of hard mineral or carbon particles in the brush material. It is desirable under certain conditions to use such an abrasive brush to assist in keeping clean the ring or commutator surface or to wear down the mica where it is not undercut. It will generally be observed that an abrasive brush has a shorter life than a nonabrasive one, other things being equal, and in this respect, abrasion built into a brush has the same net result as that considered by Hessler.

R. E. Hellmund (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Various investigators of contact phenomena are all in agreement that the oxide film forming on the slip rings in air is an important factor. A great deal of evidence has been submitted to substantiate this point of view and some additional evidence is contained in the papers presented today. However, it is difficult to explain the difference in behavior of various grades of carbons and ring materials by the oxide film formation alone. Some investigators offer in explanation of some of the differences found the presence of varying amounts of abrasive material in the carbons, and the specific resistance of the carbon material is, of course, also considered of influence. I have always felt that in addition to these factors, certain loose graphite particles may have some influence on contact resistance. (See "Sparking under the Brushes of Commutator Machines," R. E. Hellmund and L. R. Ludwig, ELECTRICAL ENGINEERING, March 1935, page 315, and my discussion of paper "Sliding Contacts—Electrical Characteristics," by R. M. Baker, ELECTRICAL ENGINEERING, July 1936, page 821.) It is rather surprising to me that this point of view has not been accepted by various investigators at least to the extent of making investigations along this line, particularly in view of the fact that they make reference to the loose graphite particles in their investigations of brush and ring wear. In an article on the subject, "Brush Wear in Hydrogen and in Air," *Electric Journal*, June 1936, page 287, Baker has advanced what appears to be a plausible explanation of certain phenomena observed in connection with the wear of brushes. In this article it is assumed that the high temperatures prevailing near certain spots of the carbon surface tend to loosen some graphite particles by the oxidation of the binding material that takes place in the presence of oxygen. Regardless of how these graphite particles become loose, there is no doubt of their presence because they can frequently be observed in practice. It would therefore seem expedient to investigate any possible influence they may have on the contact resistance.

Figure 1*A* shows the ring, brush, and oxide film and it is assumed that at *a* the oxide film has been punctured. If, as a result of this, current passes from the brush to the ring or from the ring to the brush, the highest brush temperatures will exist in this neighborhood and it is quite likely that graphite particles 1, 2, and 3 will become loose. If this occurs any appreciable distance from the edges of the brush, any theory must take into account the subsequent location and behavior of these particles. It they happen to be located in the puncture of the film as indicated in figure 1*A* they are bound to participate in current conduction and therefore will probably influence the contact resistance until they are disposed of, either by burning up or by being removed from under the brush. It is difficult to imagine that all of these particles will remain within the puncture; it is more likely that at least some of them will be carried along and thus may enter between the oxide film and the brush, as indicated by particles 4, 5, and 6 in figure 1*B*. If this condition prevails, which it is likely to do under the negative brush where as a rule

the greatest amount of brush wear takes place, the separation of the brush from the oxide film by the particles as shown in figure 1*B* would no doubt have some influence on the contact resistance and might lead to irregularities and sparking under the brush. It is not impossible that the irregularities in the contact voltage shown in figure 2*C* of the paper by Baker and Hewitt can be explained in this manner. Another possibility which should be considered is that the graphite particles are harder than the oxide film and therefore may be forced into the film as shown in figure 1*C*. Under

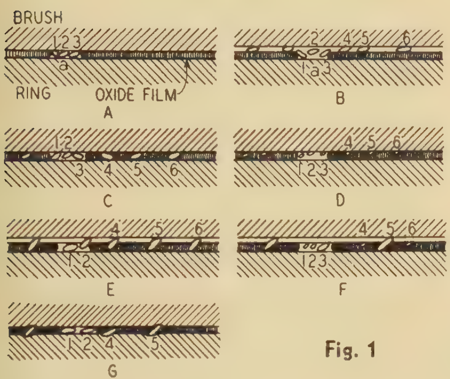


Fig. 1

this condition it is evident that these particles may form conducting bridges between the brush and the ring, and it is possible that the change in contact resistance observed with increasing current density may be caused largely by an increased number of particles acting as conducting bridges. However, the extremely short time required for decreasing the contact resistance when the current is increased suddenly, makes this possibility somewhat doubtful. It would further have to be assumed that when the current is interrupted these particles will gradually fall out thus permitting the oxide film to reform. This latter assumption is not at all contrary to observed data such as given in the papers presented.

By assuming that these loose particles have a bearing on the contact phenomena, it would seem relatively easy to explain the differences observed even in carbons having the same electric conductivity. A mere comparison of figures 1*D*, *E*, and *F*, under the assumption of relatively small particles of equal size in figure 1*D*, relatively large particles of equal size in figure 1*E*, and a combination of small and large particles in figure *F*, brings out very different conditions of current conduction. If the conditions of figure 1*D* apply, the particles may have little influence upon the contact resistance, while just the opposite might be expected with the large particles of 1*E*. Incidentally, the conditions shown in figure 1, *E* and *F* might explain some of the brush-wear data given in Hessler's paper. Differences might also be expected with the same 3 conditions of particles but under the assumption that the particles are not forced into the oxide film but merely ride on top of it. Another conceivable condition is that the graphite particles penetrate not only the oxide film but also the metal surface to a certain extent and that they lodge in the crevices of the metal ring surface as indicated in figure 1*G*. This might explain differences which have been observed with different finishes of the metal surfaces as well as differences found between ordinary cast material and other materials having a denser or harder surface structure. Finally, it seems possible that the graphite particles might dent the oxide film and force it into existing crevices of the ring without, however, penetrating it mechanically. In reality, the phenomena are probably even more complicated than indicated by any of the individual figures, as a combination of the various conditions shown in the figures may exist. As suggested in my brief discussion of Hessler's paper on "Electrical Brush Wear" (ELECTRICAL ENGINEERING, April 1936, page 406), the possibility of cuprous (red), low-resistance oxide forming in the neighborhood of the high temperature breakdown points may also enter into the phenomena. The abrasive effect of the ash particles in the carbons, previously referred to, and also the specific resistance of the carbons must as a matter of course be given due consideration.

Regardless of which of these factors are the most important under normal operating conditions, it would seem that the mechanical structure of the carbons as influenced by the number of graphite particles, their size, and the ease with which they become loose, is likely to be responsible for some of the differences observed in the contact resistance when different grades of carbons are operated on the same type of rings and under otherwise identical conditions.

V. P. Hessler: The tests of figures 8 and 9 were made at 50 amperes per square inch, of figures 10 and 11 at 120 amperes per square inch, and of figures 12 and 13 at 80 amperes per square inch. This information should have been given in the paper.

Baker's suggestion that the investigations be extended to include the effect of other gases, more brush grades, and other ring materials is in order. As suggested at the close of the paper it would be very instructive to repeat the investigations in the absence of oxygen. Perhaps a series of experiments of a similar nature, but designed to ascertain the conditions which produce electrical wear rather than abrasion would be most instructive. The cathode brush of figure 8 in the paper shows a large ratio of electrical wear to abrasion.

In every experiment performed by the author to date the anode metallic brush has always worn very much more rapidly than the cathode brush, whereas Baker has always observed the opposite effect. An extended conversation with Baker seemed to indicate that the only important variation in operating conditions was a difference in humidity. Some experiments will be performed with the lower humidity at the earliest possible date.

Baker's attempt to reconcile the action of a shirking brush on a slip-ring with the results of the paper illustrates a daily occurrence in a brush laboratory. The results of brush tests seem replete with inconsistencies when viewed from the standpoint of our present knowledge. However, it is hoped that many of these apparent inconsistencies will disappear with a complete understanding of brush phenomena.

Coover suggests that it would be interesting to obtain photomicrographs of metallic brush paths also. Only one of the slip-ring mechanisms was arranged for taking photomicrographs and it so happened that none of the metallic brush tests were made on this mechanism.

It is desirable to make the individual wear tests as long as possible, but whenever one test is extended over a longer period some other test must necessarily be deleted. The 24-hour period seemed to represent the best compromise. Actually some of the tests, in effect, were much longer than 24 hours. In figures 10 and 11 is change which was made in the operating conditions for 8 days.

May's theory that metal may be carried to the ring from the anode metallic brush has been considered as a possible explanation. The writer has planned to operate metallic brushes on a ring of some metal other than copper and study the paths carefully with the aid of microchemistry. The dissimilar metals should simplify the problem of detecting transferred materials. Of course, wear studies will have to be conducted simultaneously to ascertain whether the new material gives brush wear comparable to that with copper.

The tabulation of watts at the contact surface and wear made by Mr. May is very interesting. Previous studies made by the writer on wear indicate that there is no correlation between contact drop and wear, except in the case of a copper impregnated brush. This brush gave very similar wear and contact drop curves.

While the writer does not see any close connection between Hellmund's theory and the wear studies presented in the paper, it does relate to a very interesting observation made several years ago by a graduate student in the writer's laboratory. A very well developed "photograph" or blackened spot, had formed on a ring with a resulting high contact drop. With the hope of ascertaining the film resistance of the "photograph" the ring was stopped with the "photograph" under the brush and voltage-current data obtained. Then the ring was rotated until a normal ring surface was under the brush and the test repeated. The "photograph" showed by far the lower contact resistance and the voltage current characteristic was straight. From this the writer assumed that the black film consisted largely of carbon particles imbedded in the copper itself, but projecting through the oxide film, much as Hellmund has drawn this in figure 1*G*.

Arc Characteristics

Applying to Flashing on Commutators

Discussion and author's closure of a paper by R. E. Hellmund published in the January 1937 issue, pages 107–13, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 28, 1937.

J. N. Jones (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The methods and data given in the paper make it possible to answer various

questions regarding flashing, and one practical example may be of interest. Originally most railway motors were operated on full line voltage of 600 volts, but several years ago 2 motors in series were advocated by Westinghouse engineers under certain railway operating conditions in order to improve flashing. It was felt at the time that such improvement would be accomplished by this, but the question could not be analyzed and it required several years of experience to prove the soundness of the proposed change. With the data now available, the analytical answer to this question can be given.

In the accompanying figure, the arc characteristics for 10 to 60 amperes at a

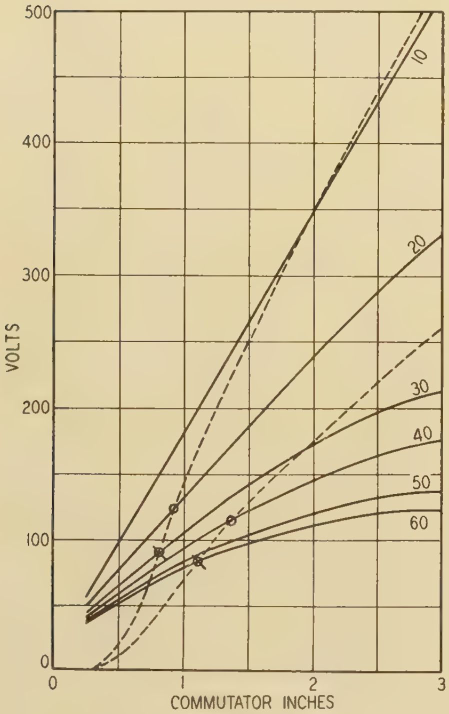


Fig. 1

speed of 2,200 feet per minute are given; the dotted lines indicate the voltage induced around the commutator, the upper curve applying to a 600-volt and the lower to a 300-volt machine. If we select a point of intersection on the 20-ampere curve of the high-voltage motor we find it to be at a distance of 0.93 inch from the zero line. The same motor operated from 300 volts would carry the same load with 40 amperes, and thus we have to find the intersection point for 40 amperes with the lower curve, This point is 1.38 inches from the zero line, which means an increase of 48 per cent and, correspondingly, a reduced tendency to flash. Similarly, the intersections of the 30-ampere curve with the high-voltage curve and of the 60-ampere curve with the low-voltage curve indicate an increase of 41 per cent. Practical experience has demonstrated that 300-volt motors are less subject to flashing in service, a fact which is somewhat in accord with the values indicated in these curves.

By a similar analysis of curves for a higher speed, 3,200 feet per minute, it was found that the distance from the zero line to the point of intersection of the 40-ampere, 300-volt curves was 44 per cent greater than that of the intersection of the 20-ampere, 600-volt curves. By a comparison of the 60-ampere, 300-volt and the 30-ampere, 600-volt points of intersection, the distance from the zero line of the first was 37 per cent greater than that of the latter.

For a speed of 1,100 feet per minute, the distance from the zero line to the 40-ampere, 300-volt point of intersection was found to be 52 per cent greater than that for the 20-ampere, 600-volt intersection. The corresponding distance for the 60-ampere, 300-volt point was found to be greater, by 46 per cent, than that for the 30-ampere, 600-volt.

From the results of these comparisons it would seem: (1) as the speed of the motors increases the advantage of having the motors in the series arrangement becomes slightly less but is still appreciable; (2) as the load becomes greater the advantage of the series connection over that of the full line voltage decreases.

R. C. Mason (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Without commenting on the interest and value to engineers of Hellmund's work, I would like to point out how some of his results can be explained in a general way by recent advances in our knowledge of gas discharges.

1. Figures 5 and 6 of Hellmund's paper are a little misleading where they show arc voltage increasing continuously from zero. Actually, as soon as an arc is drawn, a definite arc voltage develops, and the curves should start at that point. Even fairly high-speed cathode-ray oscillograms show that the voltage across a pair of opening contacts suddenly increases from a low contact drop to an arc drop of some 10 or 12 volts.

2. When the current through an arc of constant length decreases, the arc voltage changes in a manner which depends on the speed with which the current reduces: the arc voltage will be lower, the more rapidly the current decreases. In these experiments, however, where an arc is drawn by a moving commutator, an increase in arc length accompanies (causes) the decrease in current. While perhaps the losses from the arc may be influenced because air currents about the arc vary with commutator velocity, it seems that the predominant effect upon the arc voltage when the arc has reached a definite length and current must come from the speed with which the arc has been lengthened. How this may result can be seen by considering 2 extremes: suppose an arc for which the gradient in the positive column is 10 volts per centimeter has its length increased *extremely slowly* by one centimeter, while the current remains constant; the arc voltage will merely increase by 10 volts. If, however, the arc length could be *instantly* increased one centimeter, by the introduction of one centimeter of cold unionized gas, then the arc voltage would increase by the many thousand volts required to break down the one centimeter of cold gas. Of course, the latter extreme is never realized in practical cases of arcs on commutators, but the point is that whenever a new length of positive column is created, the voltage required to maintain any particular current in that length depends upon the temperature and state of ionization of the gas. If the arc lengthens quickly, the temperature and degree of ionization of the gas in the newer parts of the positive column lag behind those of the older parts; hence to maintain the arc, a higher gradient must be applied in the newer than in the older parts. If, however, the arc length increases gradually, the energy lost from the older parts of the positive column has time to flow into the newer parts, and not much increase in gradient arises. Thus, the arc voltage should increase with increased speed of drawing of the arc, just as shown in figure 7.

3. In the experiments described in the last part of the paper, the cathode or anode spots cannot actually move continuously over the commutator, because of the insulation between bars. Hence for advancement, new arc terminals must form. It is well known that a new cathode spot will not be established unless the electrode is at a potential considerably negative with respect to the adjacent arc stream, but it is perhaps not generally appreciated that likewise a new anode terminal will not form until the electrode is several volts positive. Figure 12*A* illustrates this very well; on the right side, no current flowed to the first bar from the shorted sector, the arc anode transferring directly to the second bar. In this case, it was necessary for the new electrode to be at least some 15 or 20 volts positive with respect to the adjacent positive column in order for the new anode to strike. The commutator bars are cold, while the gas in the arc column is at some 5,000 degrees or 6,000 degrees, so no matter how closely the arc stream hugs the commutator, always a transition region exists in which the gas temperature falls from the high value of the arc to the low temperature of the metal. Through reduction of electron mobility within the cold gas, the flow of current is so impeded that considerable voltage must be applied across this region in order to carry the full arc current and establish a new anode spot.

At a new cathode spot additional requirements, not well understood, must be met which demand even a higher voltage than at the anode. Thus in figure 12*B*, left, not even the voltage drop across 2 commutator bars, perhaps some 30 to 40 volts, was sufficient to transfer the cathode. In figure 12*C* and *D* the sudden breaks in the arc voltage give a measure of the voltage required to strike the new cathodes; these range from 30 to 175 volts, while even higher voltages in some cases caused no transfers.

R. E. Hellmund: The discussion contributed by Jones indicates how the data presented in the paper can be used to advantage to clarify certain practical questions.

Mason's reference to figures 5 and 6 of the paper is quite correct. These curves should start somewhat above the zero line if they are to represent arc voltages; they were extended to the zero line merely to indicate the starting current on which the curves were drawn. His other remarks are exceedingly interesting and give some very valuable explanations of the arc phenomena.

Penney's discussion indicates that with a roughness of 0.0003 the brushes may leave

the commutator a distance of one or two inches. Everybody familiar with railway practice knows that a figure much greater than the one given by Penney has often been allowed for the roughness of commutators, especially in some of the older motors. It therefore seems that a great deal of the commutator flashing in practice can be explained by commutator roughness, which supports the feeling I have had for some time that other causes, such as shocks caused by rail joints or mechanical vibrations of the motor as a whole, are of minor importance. The conclusion to be drawn from this is that commutator maintenance is possibly of even greater importance in reducing flashing in railway motors than any changes in the design of the motors. A review of the data given in the paper plainly indicates that flashing may occur with any motor design no matter what the field form of the motor may be. In railway work, space limitations make it practically impossible in the smaller motors to make the total distance between brushes more than

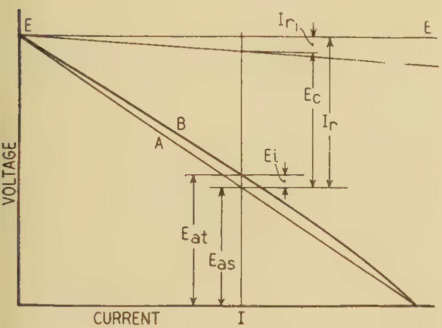


Fig. 2

5 or 6 inches, and since the total counter-voltage of the motor has to be induced within the distance between the brushes, the arc is likely to be drawn into the high-voltage region if the brush is off the commutator long enough.

Since it was not done in my paper, it may be well to call attention here to the fact that the transient arc characteristics as determined in the paper are not entirely independent of the circuit constants of the test arrangement. This may be illustrated by reference to the figure in this discussion. If a total voltage E is impressed on the circuit, the ohmic drop in the circuit can be represented by the distance Ir between the horizontal line EE and the curve A. Curve A must obviously be a straight line because the ohmic drop is proportional to the current. This simply means that with stable arc conditions the arc voltage E_{as} is represented by the difference between the impressed voltage and the ohmic drop. If we consider, however, transient current conditions with a decreasing current, and if there is any self inductance in the circuit at all, a self-inductive voltage E_i is induced, leading to a voltage E_{at} for the arc voltage. This is the condition found in figures 5 and 6 of the paper. It is therefore evident that under transient conditions, the value E_i will depend to some extent upon the inductance in the circuit. In a series motor, which is of the greatest practical importance in this study, conditions are different but the final results are somewhat similar. Instead of the large ohmic drop Ir, there is a small drop Ir_1, and in addition there is a counter electromotive force E_c which is proportional to the current, at least as long as the motor is not saturated. The net result is that the sum of Ir_1 and E_c is about equal to Ir, and the effect of any self induction is again represented by the value E_i. Under transient conditions the counter voltage may be influenced temporarily to some extent by the damping effects of the eddy currents in a solid frame portion upon the flux. Nevertheless, it is believed that the experimental data given in the paper are quite applicable to series motors, although it may be inadvisable to assume without further investigation that the same curves can be applied indiscriminately to entirely different conditions.

Contact Drop and Wear of Sliding Contact

Discussion and authors' closure of a paper by R. M. Baker and G. W. Hewitt published in the January 1937 issue, pages 123–8, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 28, 1937.

R. E. Hellmund: See discussion, page 602.

V. P. Hessler (Iowa State College, Ames): The results presented in this paper are very interesting and worthwhile as a step toward the ultimate goal of a complete understanding of sliding contact phenomena. The importance of the oxide film in contact drop phenomena seems to be definitely established by these and the former investigations of one of the authors. However, a large amount of experimental work will have to be done before the relative importance of the various factors involved in contact drop will be determined. For example, the oxide film alone does not explain the difference in contact drop obtained with the various grades of brushes. The difference might be attributed to abrasion but this seems hardly likely in view of the following simple experiment performed by the writer.

A pair of electrographitic brushes had been operated on a copper ring for several days with a current of 50 amperes per square inch. Then the ring was cleaned with fine carborundum paper and contact drops obtained simultaneously with the following results shown in table I of this discussion.

While the above indicates that abrasion does have an effect upon contact drop, the

Table I

I	E_+	$E_\pm$	E_-	
50	0.68	1.57	0.85	Before sanding.
50	0.68	1.45	0.77	After sanding lightly.
50	0.67	1.40	0.73	While sanding with 360 grit.
50	0.69	1.48	0.80	Running 2 minutes since sanding.
50		1.20		While sanding with 280 grit.
50	0.66	1.42	0.76	Running a few minutes since sanding.
50	0.52	1.10	0.58	While sanding with 280 grit.

results were not nearly as pronounced as were expected. The abrasive paper must have cut through the oxide film, and the re-established film must necessarily have been of molecular dimensions considering the time required for an eighth of a revolution at 1,600 revolutions per minute.

The authors suggest the possibility of a quasi-electrolytic action as a factor in ring wear, but show that the amount of material transferred is negligible compared to that in ordinary electrolytic action. In the case of brushes, the rate of wear is often not even proportional to the amount of current flow. With brushes not tracking the cathode metallic brush and the anode graphite brush always showed rates of wear independent of current density in the tests made by the writer. Of course, this does not apply to excessive values of current density.

The authors also suggest that, since there is less ring wear at the cathode section of the ring than at the zero-current point, material may have been picked up from some other part of the ring and deposited on the cathode section. It seems more logical to the writer to consider that the abrasion has been less at the cathode section than at the zero-current section. Very often a commutator will become threaded and the brushes dust under light loads, whereas these difficulties will all disappear under full load conditions. The same phenomena may be occurring in this synchronously operated ring.

The effect of operating sliding contacts in inert gases is indeed interesting. It will be another important step in advance when it is learned just why the presence of oxygen produces such a large increase in brush wear. The writer sincerely hopes that the authors will consider it worth while to repeat some of their experiments with a trailing brush to determine the importance of abrasion in this phenomena. It would also be interesting to analyse the gas in the tank for CO and CO_2 after a period of operation.

R. M. Baker: Hessler cites experiments in which he sanded slip rings while the brushes carried normal current, and found that the sanding operation resulted in only a small reduction in contact drop (contact resistance). It was inferred from this experiment that the oxide film is not an important factor in determining contact resistance. It must be pointed out, however, that quite different results would have been obtained if the experiment had been performed with a few milliamperes instead of normal current flowing in the contact. With normal current flowing through the contact, the film was already broken down to such an extent that sanding the ring had little effect. Sanding the ring with very low current flowing in the contact will some times result in a 1,000-to-one change in contact resistance.

It was unfortunate that the authors used the word "electrolytic" in describing the material transfer indicated in figure 5, for this word indicates the existance of an electrolyte. It was thought more likely that the material was transported by gaseous metal ions produced in the contact by vaporization, or some other process. The unequal wear might occur as Hessler and several others have suggested simply by nature of the fact that the abrasive effect of the brush

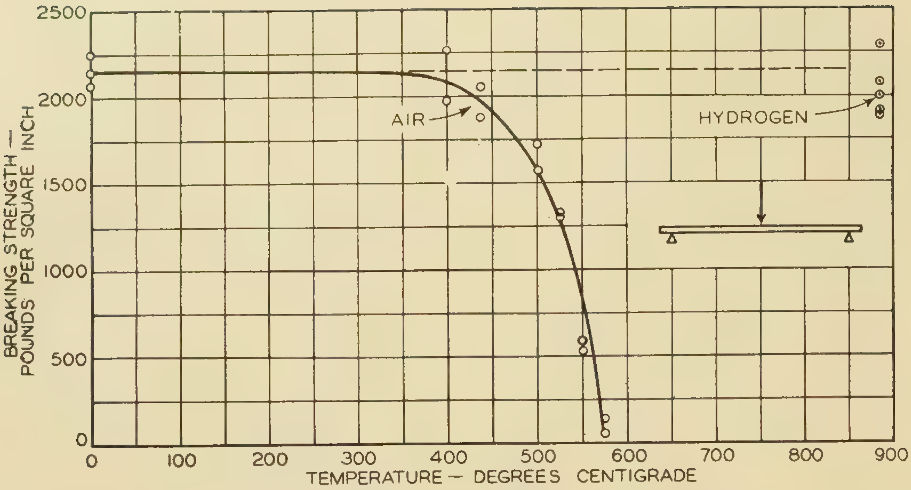


Fig. 1. Effect of oxidation on the strength of carbon material

is different over different parts of the rings, depending upon the amount and direction of the current flowing. There are 2 facts, however, which indicate very strongly that there is actually a transfer of material from the ring to the brush and vice versa. First, the polarity at which rapid ring wear occurs is correct for material transfer by positively charged metal ions; secondly, the variation in the wear curves is very nearly proportional to the current. If the results are to be explained on the basis of abrasion, it is necessary that the abrasion be not only dependent upon the direction but also upon the magnitude of the current.

Hessler mentions the fact that the brush wear data which he has obtained for metal graphite brushes cannot be explained by the picture of material transfer given above. This is to be expected, because brush wear is hundreds of times more rapid than ring wear and the small component produced by material transfer in the contact would never be noticed. This also raises another possible point of question which should be straightened out. Since the brush wears so rapidly, it is unlikely that much of the copper picked up off the ring would ever be redeposited. Thus, if copper is deposited on some part of the ring surface it probably is copper originally included in the body of the brush.

Some experiments with trailing brushes in an oxygen-free gas will be made as suggested by Hessler. It is doubtful, however, if such tests will give any evidence as to the process whereby brush wear is reduced upon going from air operation to operation in some oxygen-free atmosphere.

The authors have talked often about making an experiment to determine the amount of carbon monoxide and carbon dioxide given off by brushes during operation in air or in oxygen but have never found time to make the experiment. Such an experiment would furnish interesting information.

Hellmund has rightly brought out the fact that investigators of carbon brush problems have neglected to consider the effect of the carbon or graphite particles which are continuously being set free in the contact through the process of brush wear. If one assumes that all the brush wear results from particles 0.0001 inch in diameter being torn out of the brush face, one calculates that, for normal brush wear, about 50 to 100 particles are liberated from each square inch of brush area for each foot of travel. This gives some idea of the number of particles released in the contact during normal operation in air. It is surprising when one realizes that on the above assumption a brush one square inch in area, operating on a ring with a speed of 5,000 ft. per minute, would give off half a million particles in one minute.

It is not known just how these particles leave the contact or what part they play during the time they are in the contact. Hellmund makes a number of interesting suggestions, and following these, an investigation will be undertaken by the authors to determine experimentally the size and number of the particles given off by different brushes.

Hellmund suggests that the roughness of the voltage records (figure 2 of paper) for the negative polarity might be explained by the movement or disappearance of loose carbon particles in the contact. It will be seen, however, by a comparison of alternate periods of the voltage wave (figure 2 of paper) that the variations are a function of the ring position and must therefore be due to some condition existing on the ring surface rather than in the brush face. This same effect is even more noticeable during d-c operation where the voltage drop record repeats almost exactly over successive revolutions when 3 or 4 revolutions are observed on one oscillogram.

Hellmund mentions an earlier article in which the authors suggested that oxidation of the brush material immediately adjacent to the contact resulted possibly in a weakening of the brush structure and the high rate of brush wear commonly observed in air. Further evidence along this line is given by the curves of figure 1 of this discussion.

To test the weakening effect produced in a brush material by exposing it to various temperatures in air, the following experiment was made. Samples of an electrographitic lamp-black, $^1/_2$ inch wide by 3 inches long by $^1/_{16}$ inch thick, were subjected to various temperatures for 20 hours in an electric furnace. These samples were later subjected to a breaking test with the results indicated in figure 1. The strength recorded is the modulus of rupture in pounds per square inch.

It will be seen that in air the material began to loose its strength around 350 degrees centigrade and had zero strength around 570 degrees centigrade. Even the samples which had zero strength, still retained essentially their original size and shape and it seemed as if the weakening had occurred by a surface oxidation of the individual particles of the brush to weaken the bonds until the sample was just ready to fall apart. In hydrogen, similar samples were heated up to 880 degrees centigrade with practically no weakening. This is in line with previous arguments and is a little more evidence that oxidation of the brush material adjacent to the contact is an important factor determining the rate of brush wear in air.

In closing it should be mentioned that R. Holm of the Siemens Company in Berlin made experiments some years ago which demonstrated some of the results given by figure 2 in the paper. A copper ring was operated with a low value of direct current until the contact resistance was high. The ring was then stopped and part of the surface was subjected to a heavy current. Afterward the ring was allowed to run with only a small current flowing while the contact drop was observed with the oscillograph. The variation of contact drop around the ring showed that the section of the ring surface which had been subjected to the heavy current continued for some time to offer a much lower resistance to the flow of current than did other sections of the ring surface. The results of this experiment were never published but were communicated verbally to one of the authors during his visit to Berlin in 1932.

Self-Regulated Compounded Rectifiers

Discussion and authors' closure of a paper by W. Melvin Goodhue and R. Burton Power published in the November 1936 issue, pages 1200–5, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 28, 1937.

F. N. Tompkins (Brown University, Providence, R. I.): The authors are to be congratulated for producing such a timely and interesting paper.

Since little mention was made of a single-phase full-wave rectifier working in the manner described in the paper, it was thought worth while to set one up in the laboratory. It was found to give results comparable with those given in the paper. For instance, with a straight rectifier, i.e., not self-regulated nor compounded, when the input voltage was varied from 150 to 250 volts the output voltage varied from 102 to 178 volts. With the input voltage held constant at 230 volts and the load varied from zero to full load, the output voltage varied from 184 to 159. With the rectifier self-regulated but not compounded, a variation of input voltage from 150 to 250 gave a change of output voltage from 97 to 119 volts. When the input voltage was held constant at 230 volts a variation of load from zero to full load gave an output voltage change from 119 to 115 volts. It is quite possible that with changes in the apparatus

used even better results would have been obtained. These tests, besides indicating that the circuit may well be used with single-phase input, pointed out several facts which either were not stressed or were not mentioned by the authors.

The current transformer used in the 3-phase arrangement seems to be of special design, being for 3-phase operation. Three common single-phase current transformers should not be used since they would be working into a half-wave rectifier and would have no secondary load every alternate half cycle. This would lead to saturation of the cores and a high voltage drop across the primaries. In the single-phase compounded rectifier, as set up in the laboratory, it is necessary to use a current transformer with a center tap in order that the current compounding may be supplied from a full-wave rectifier. It was also found to be advisable to filter the output of this rectifier for best results, a choke and condenser being used for this purpose.

The ratio of the main transformer must be carefully chosen when designing a rectifier of this kind. To secure either voltage compensation or compounding, it is necessary to operate the rectifier at some lower voltage than would normally be given by the chosen transformer ratio. This is necessary in order that the regulating voltages from the drop wire across the output and from the current-transformer rectifier may have control of the grids of the tubes. The amount of voltage below normal at which the rectifier unit must operate depends upon the amount of voltage regulation desired.

In the paper small lamps are shown in the grid circuits acting as protective resistors. In the single-phase arrangement it was found advisable to use much higher values of resistance than is represented by these lamps, 5,000 ohms being a good value. The grids should not take any more current than is necessary.

L. A. Kilgore (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The authors describe a method of automatically controlling the voltage of grid-controlled rectifiers, which utilizes the output voltage of the rectifier to control the grids. The authors show a smoothing inductance which takes out part of the pulsation of output voltage. If the smoothing action is not complete, the grid picks up when the output voltage is at the minimum point. Hence, it attempts to regulate for a constant minimum voltage. The difference between the average and minimum voltage will be the function of the load current, load-circuit inductance, and resistance. The authors describe a means of compounding which takes care of the change due to load current. The writer would like to ask whether or not they would expect changes in average voltage if the character of the load circuit changed, especially if the load inductance changed.

If the ripple in the output voltage was completely filtered out, then any slight variations in the critical voltage of the grids would cause wide variations in the firing of individual anodes and cause serious unbalance of load. It would seem that to keep the same accuracy of firing, the ripple voltage must be of the same order of magnitude as the sine wave grid voltages which have been previously used for controlling the firing of grids. If this is true, nothing is gained over the conventional method of impressing grid voltages from a grid transformer, and it has the disadvantage of being dependent on such factors as the inductance of the load circuit. The writer would appreciate the authors' comments on these points for it may be that some of the functions of the apparatus described have been misunderstood.

When considering the control of rectifier voltage by grids, whether automatic or manual, it should be observed that any reduction of voltage is accompanied by a nearly proportional reduction in power factor, and an increase in harmonics. This fact somewhat limits the general application of such control, but the writer feels that there will be numerous applications where the automatic control of rectifier voltage will be used. Several automatically regulated rectifiers have been built, one using a conventional current regulator, such as might be used on a rotating machine. Another rectifier using voltage and current compensation was found to give very flexible control of the regulation characteristics.

Didier Journeaux (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): The authors are to be given credit for presenting a method of rectifier control of sufficient interest to make their readers desirous of obtaining additional information on the details of the process of operation of their system. In particular, curves would be desirable showing the different characteristics obtained by varying the voltage of the bias battery and the tap of the potentiometer, and by maintaining the tubes in an oil bath at different constant temperatures. Oscillograms of the input and output voltages, of the d-c load current and of the grid voltage during steady state operation and during transients would also be of assistance in obtaining an insight into the action of the grids. The omission of a d-c load-smoothing inductance in figure 7*b* appears to be inadvertent.

While the results reported by the authors are quite interesting, it is necessary to bear in mind the limitation to which the system is subject. In particular, the action of the grid control relies on the curvature of the grid characteristic and is of extreme sensitivity. This renders the system easily disturbed by any irregularity in the action of the tubes to the extent that, in some of the circuits, tubes must be selected and perhaps also matched to give reliable results. If the grid characteristic is subject to variations, the output voltage or current will receive the same variations amplified in a constant ratio. This would probably render the regulator entirely inapplicable to the control of rectifiers of the mercury-pool type, for which mechanical regulators of the rocking sector type have been found entirely satisfactory. Such regulators have been used with great success in this country and abroad for controlling constant voltage, compounded, and constant current rectifiers, the latter being utilized in some large electrolytic plants. While rocking sector regulators have not been used on currents requiring regulation through a load range including short circuits, they are perfectly adapted for that purpose. By the addition to the regulator of a high-speed relay, regulation could be maintained through suddenly applied short circuits within such limits and at such speeds as to meet the requirements of most practical applications.

C. L. Dawes (Harvard University, Cambridge, Mass.): During the past few years it has become increasingly evident that ionic devices were certain to replace relays, certain types of rotating machinery and many types of regulating devices. For example, in new substation installations, the mercury-arc rectifier has virtually superseded rotating machinery in the conversion of alternating to direct current. Because of the absence of rotating elements, windings and iron cores, such rectifiers are inherently more efficient, especially so at light load, and are much lighter than equivalent rotating machines. Moreover, because the ions constituting the rectifying medium have insignificant inertia, and respond with extreme rapidity to both electric and magnetic fields, it is possible to obtain characteristics, and to control current and voltage in a manner which is impossible with rotating machinery. This paper by Goodhue and Power is an excellent illustration of some of the results which can be obtained with such ionic devices.

I am first calling attention to the method of grid control which they employ as is illustrated by figures 1*a*, 1*b*, and 7*a* and 7*b*. The usual method of grid control is to apply an alternating electromotive force to the grid and to control the instant of firing either by shifting the phase of this electromotive force, or by changing its magnitude. The authors obtain greater sensitivity, less effects from temperature, and more positive action by connecting all the grids together and applying a direct-current voltage to them. This electromotive force is supplied jointly by a constant source of electromotive force, such as a battery, and a potentiometer connected to the d-c system supplied by the rectifier. As the authors state, the regulator operates so rapidly that the pointer of a d-c voltmeter shows no noticeable flicker with large and sudden changes in input voltage.

By the addition of current compounding a wide range of voltage-current characteristics may be obtained, from almost any desired degree of cumulative compounding to almost any degree of differential compounding as shown by figure 3. Also constant-current characteristics and characteristics combining constant-current to the limit of the rectifier operation and then through nearly constant potential to zero current all may be obtained merely by suitable adjustments of the shunt and series regulating resistances as shown by figure 4.

Hence it appears that these methods offer possibilities in industrial motor control, not readily obtainable with the usual d-c sources. As pointed out by the authors, by the use of the characteristics of figure 4 motors may be started with any desired value of constant torque and brought smoothly up to rated speed. All starting equipment is eliminated together with the pulsations in starting current caused by the intermittent closing of contactors. The method makes possible by simple means the precise control of many processes which control heretofore was only possible by

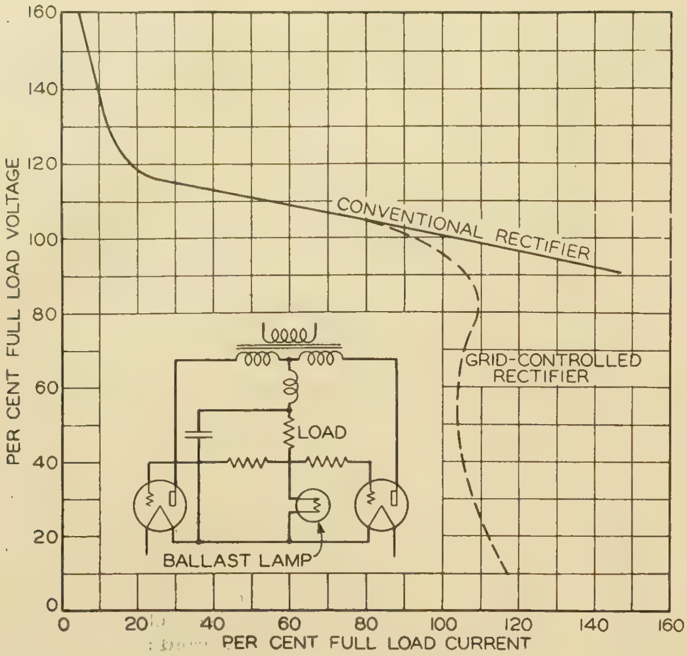


Fig. 1

means of complicated and cumbersome electromagnetic control equipment. As an example, if it were desired to maintain the speed of a motor constant it could be separately excited and a direct-current magneto connected to the shaft. The terminals of the magneto would be substituted for the potentiometer *S*, figures 1*a*, 1*b*. Any change in speed of the motor would change the electromotive force applied to the grids, and the electromotive force at the motor terminals would change correspondingly. If compensation for the small effects of temperature on the critical grid voltage were desired, a slight degree of current compounding could be introduced, using the connections of figure 1*b*. There are many other applications of such automatic control such as maintaining the correct distances in alignment processes, controlling temperature and pressure, etc.

Heretofore constant direct current has been obtained by means of the constant-current transformer supplying constant single-phase current to single-phase rectifiers. As shown by figure 4 the methods developed by the authors make it possible to obtain such constant direct current from a polyphase rectifier, with advantages over the constant-current transformer method. The moving coil with the accompanying mechanism is eliminated. The constant-current transformer cannot maintain constant current during sudden changes of load. With the moving coil in any fixed position the current locus is a circle. Hence the coil must move to maintain constant current, and, owing to the inertia of the mechanical system, considerable time is required for readjustment of the position of the coil. With the system shown by the authors, response to load changes is practically instantaneous. Moreover, their system constitutes a balanced 3-phase load whereas the single-phase, constant-current transformer produces unbalancing in 3-phase, systems which under some conditions may be objectionable.

To my mind this paper is valuable, not only in showing the definite characteristics that are obtainable with a controlled mercury-arc rectifier, but it also shows the flexibility that is obtainable by means of ionic control devices and it opens up wide possibilities in the field of industrial power applications.

Reuben Reiter (Harvard University, Cambridge, Mass.): The data presented in the curves of this paper show that the maximum power controlled by the authors in their experiments was of the order of 2 kw. It is desirable to know the economics of this method of control when applied to much larger blocks of power. The dollars and cents saved by this method over other existing methods will determine its present value.

Would it not be possible to economize on the initial cost of the control installation by employing a single phase for control rather than 3 phases. The system shown by the authors employs 3-phase transformers and requires 3 rectifying units to supply the d-c control voltage. The method is a balanced one, but is it necessary for the ordinary installation.

G. H. Rockwood (Bell Telephone Laboratories, Inc., New York, N. Y.): The compounding circuits suggested by the authors are of considerable interest since they permit of cumulative compounding so conveniently. As the authors suggest differential compounding makes possible the construction of a rectifier which may be used for d-c motor control, or one the output of which may be short-circuited without damage to tubes or associated equipment. Because of the convenience of differential compounded circuits it seems pertinent to call attention to another type of circuit which makes possible differential compounding in a cheap and simple manner. The circuit for a single-phase rectifier is shown. In this circuit the load current is passed through a series resistance, the drop across which supplies the grid excitation for the rectifier tubes. If this series resistance is a nonlinear device such as a tungsten-filament ballast lamp, the voltage drop across it even at full-load current may be made small enough so that the grids have very little negative bias, but for overload currents the grid bias rises rapidly. Because of the curvature of the grid characteristics of negative grid tubes, a small grid bias causes practically no change in output of the rectifier. Consequently, the load-regulation characteristics for the conventional rectifier and the differentially compounded grid-control rectifier are substantially identical except in the overload region. It will be observed from the figure that the rectifier may be short-circuited without having the load current rise to excessive values. It should be added that the rectifier operation is stable even under short circuit conditions.

Myron Zucker (Detroit Edison Company, Detroit, Mich.): The authors are to be commended for trying to apply the inherent speed of electronic equipment to work-a-day jobs. Such development, especially toward simplification, is needed if industry is to profit by electronics. Despite the quick action theoretically obtainable with electronic regulators and controllers almost all regulating work can still be done more economically by other means. Even in such a wide-open field as the high-speed regulation of distribution circuits to eliminate lamp flicker, no satisfactory regulator has yet been developed: it is still necessary to resort to the "brute force" method of making every element in the circuit oversize. As long as transformer capacity and copper come cheaper than tubes, there can be no quarrel with the present method of handling the situation. Perhaps a continual assault on the regulation problem will some day produce more refined solutions.

However, despite the desirability of the study, the authors' solution seems to be limited to certain special applications. Several factors seem to make it unsuitable for commercial work.

The first control scheme described in the paper is the most attractive because of its simplicity. It depends on balancing the output voltage of the rectifier against a battery, to energize the grids. This has 2 disadvantages:

1. An ordinary battery is not as reliable a long-time voltage standard as is commonly considered, so that—especially with the sensitive differential principle used in the grid circuit—erratic operation is likely to occur. How much current—instantaneous and average—and in which direction—was drawn through the battery?

2. Ripple is demanded in the output voltage. Although too much is undesirable, it is obvious that too little would be even worse. In the extreme case of no ripple, the average voltage would be obtained from a series of "full on" operations followed by all tubes being entirely "off" for several cycles.

It would help if the authors would tell how much ripple they have found desirable in their tests, and also whether they have run any tests for extended periods of continuous operation. Also, what magnitudes of battery voltage was used? How do the values depend on load, voltage, and the range covered by these? What are the quantitative conditions for figure 2, the curve showing perfect regulation? Can this curve be reproduced at will for various

loads and voltages? Once the proper adjustment has been made for a certain voltage-load characteristic with a given supply voltage, will a similar curve be obtained for a different value of supply voltage?

It seems that the ripple might be reduced by placing filters on the load side of the control potentiometer *S*. Have the authors tried this? Since a certain minimum of

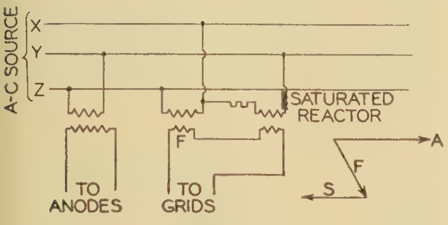


Fig. 2

ripple is required for control, is it not true that the ripple is worse with this type of control than with other types unless such filter can be used?

Use of tubes that "fire" with negative grid voltages is suggested by the authors. This might better some of the curves and permit use of weaker grid circuits (or ease the battery service), but would increase the chances of erratic operation. These "negative grid" tubes have a tendency toward random firing even with the best of grid excitation; it might be too much to expect them to give good service on the slim margin provided by voltage balancing.

It might be suggested that similar curves including compounding have been obtained in a more reliable way by a-c excitation. For instance the circuit shown in the diagram will give very close regulation. "Compounding" can be added with phase adjustable, giving a wide range of characteristics available. Such a control circuit has been applied to rectifiers and to excitation of an alternator. In the latter case, an added feature is that overspeed may be made to remove excitation and trip the main alternator circuit breaker. This type of circuit does what the authors set out to do—control without auxiliary tubes—and at the same time provides a definite, predictable voltage to the main grids.

W. M. Goodhue: Tompkins reports verifying the circuits given in the paper with a single-phase circuit in his laboratory. The authors appreciate the interest which he shows, particularly in view of the difficulties encountered in a different laboratory not having equipment specially designed for this new circuit. For example, the amount of smoothing inductance must be co-ordinated with the rectifier circuit in order to obtain a specified uncompensated characteristic.

The current transformer is stated in the paper to be polyphase. It would naturally follow that, with a single-phase set, transformers with the center tap would be employed. In filtering the pilot rectifier, it should be remembered that too much grid filtering will introduce time lag, and Tompkins perhaps uses grid filtering to compensate a long commutation period in the main rectifier.

In all grid-controlled rectifiers and inverters it is usual and essential to employ a main transformer turn ratio giving a maximum d-c voltage greater than the operating voltage. Even in a d-c dynamo, the shunt-field coils are designed for 80 per cent or so of full voltage, the remainder being absorbed in the field rheostat.

The value of grid resistance to be used depends on the choice of tubes, and must be co-ordinated with potentiometer resistances. Tompkins may have used a different type of tube than the authors. Also, the value of resistance is not critical.

L. A. Kilgore asks whether the authors would expect any change in average voltage if the load *inductance* is changed. This condition is peculiar in that *load* inductance, unlike the smoothing inductance, is outside of potentiometer *S*. This tends to *increase* the *voltage* ripple across potentiometer *S*, and hence the average voltage. This effect may perhaps be overcome by the insertion of condenser-resistance filtering in the contact *S* lead, in place of smoothing inductance in the power circuit.

The question of the accuracy of firing does require expounding. Inspection of curves, such as figure 2, shows *extraordinary accuracy* all out of proportion to any results obtainable with *static* grid circuits having similar magnitudes. Protective devices were employed in these experiments and would have shut down the equipment if serious anode unbalance ever occurred. No shutdown due to unbalance occurred, showing that this effect was not serious. The peak current equals the load current, so that only firing-time unbalance need be considered. Kilgore neglects the fact that unbalanced firing would produce an *unbalanced ripple.* The resulting regulator action would automatically restore balance immediately. In other words, failure of a tube to fire at the appointed time causes the ripple to continue dipping *beyond* the appointed time with accelerating downward slope, forcing the tube to fire close to the appointed time.

Therefore, ripple voltage in this circuit may be much smaller than the sine-wave voltages usually employed in grid circuits. Of course, if *complete filtering* is desired, it can be added in the d-c load itself *beyond the potentiometer S*, without depriving the grid circuit of ripple.

With large ripple, compounding would still work, and high voltage sets (250 volts up) would have a small *per cent* ripple and hence regulate. The authors agree with Kilgore that the advantages of grid control far outweigh the reduction in power factor.

Didier Journeaux suggests oscillograms for the purpose of understanding the grid action. Different states of operation are possible, all satisfying the equations of the paper and giving the regulator action. The extraordinary accuracy (figure 2) compared with the small ripple voltage operating the grids would require special experiments to understand. Artificial variation of critical voltage of one tube must be introduced.

Therefore, the number of oscillograms and amount of research would be so large as to properly belong in a second paper on the subject.

The omission of smoothing inductance in figure 7*b* was probably due to the custom of combining interphase transformer and smoothing inductance by the use of a high-leakage interphase transformer.

The characteristics varying the potentiometer taps and bias battery are shown in figures 3, 4, and 6. Only slight improvement with oil bath may be expected, since other factors such as per cent ripple still vary with current.

The question of tube irregularity and grid variations has been considered in answer to Kilgore's discussion. The grid control does not rely on the curvature of the grid characteristic. The authors wish to thank Journeaux for calling attention to the fact that mechanical regulators can possibly be designed for high speed, where the grid current to be controlled is small. However, such regulators are limited economically to large size rectifiers.

G. H. Rockwood has a very interesting differential-compounded rectifier. It seems to depend directly on the grid critical voltage and hence be subject to wide variations with temperature and supply voltage. In the dotted curve portion, the current varies considerably, while the authors' characteristics are linear (figure 4) with nearly constant current. This is because the use of a bias battery in the authors' circuit reduces the per cent of variation due to critical grid voltage. For example, assume a critical grid voltage of 5, which varies say one volt, and a battery of 90 volts. For Rockwood's circuit, 1 volt in 5 is 20 per cent variation; for the authors' circuit, 1 volt in 90 is 1.1 per cent variation. With a 180-volt battery, the variation is only 1 volt in 180 or 0.55 per cent. Thus, the use of a bias battery or its equivalent is essential in any d-c controlled rectifier circuit to eliminate grid variations. The use of a tungsten-ballast filament introduces time lag, especially for currents of 5 or more amperes; this lag is minimized by operating smaller filaments in parallel. The power loss in the ballast probably equals the tube loss, limiting application to small equipment, where first cost rather than efficiency is important. Of course, voltage regulation and cumulative compounding are not obtainable.

C. L. Dawes offers a very illuminating discussion of the industrial applications of the new circuit, and also the principles of operation. As he states, the moving-coil type of constant-current transformer is practically helpless during a rapid change, and reverts to an inferior circle-diagram characteristic. When the moving coil is near the stationary coil, the dynamic charateristic is especially inferior, the short-circuit current being several times the operating current, because the reactance is low. The authors feel with Dawes that the flexibility of grid control methods is enhanced by the new circuit.

Reuben Reiter evidently wishes the authors to discuss economics of this circuit. With large blocks of power the following relations exist:

1. Entire control-circuit kva and power loss is negligible. No phase shifters are necessary. Therefore, the expense of control equipment, both initial cost and operating cost, is very small compared to the main equipment.

2. Other methods of obtaining constant current from a constant-potential source are expensive, such, for example, as moving-coil transformers, monocyclic networks.

3. In addition, the dollars and cents problem involves other factors introduced in connection with the purpose of the equipment, the facilities available, and the financial nature of the application. Obviously, too general statements are misleading.

Reiter also suggests a single-phase control with polyphase power. To avoid throwing the power anodes out of balance, considerable filtering of the pilot rectifier may be necessary, with resulting time lag. Initial cost is usually vital in small installations. For these, the *entire power equipment* may be single-phase, the pilot rectifier may consist of a *cheap full-wave radio tube* (type 83, 83*v*, or 80), and the current transformer of inexpensive power-pack construction.

Dyadic Algebra Applied to 3-Phase Circuits

August 1936 issue, pages 876–82

Complex Vectors in 3-Phase Circuits

December 1936 issue, pages 1356–64

Discussion of 2 papers by A. Pen-Tung Sah published in the August 1936 and December 1936 issues and presented for oral discussion at the tensor analysis session of the winter convention, New York, N. Y., January 26, 1937.

Giuseppe Calabrese (The New York, N. Y. Edison Company, Inc.): When new methods of analysis are applied to any branch of science, the first step taken is that of explaining well-established facts with the new methods. In this respect, and in connection with Sah's papers, perhaps, it may be of some interest to derive the formula of the force between 2 elements of conductors carrying currents, in the light of the theory of dyadics, and to show how this force may be visualized as being proportional to the direct product of a vector by an antiself-conjugate dyadic.

With reference to the figure below, let $\dot{I}$ and $\dot{I}_1$ indicate the magnitudes and space directions of the currents flowing in the 2

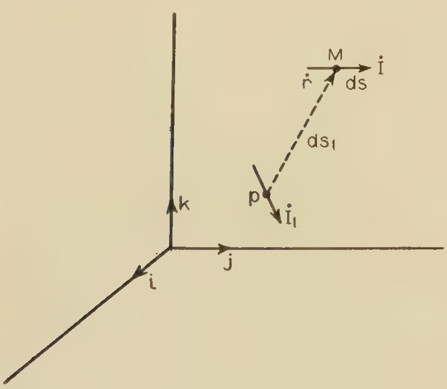


Fig. 1.

elements ds and ds_1 of the 2 conductors located respectively in M and P. Let $\dot{r}$ be the vector PM positive from P to M.

The force $\dot{F}_0$ exerted on the element ds_1 of the conductor carrying the current $\dot{I}_1$ by the element ds of the conductor carrying the current $\dot{I}$ is given by (the dot on the letters $\dot{I}$, $\dot{I}_1$, $\dot{r}$, $\dot{F}_0$, is used to indicate vector quantities. The same letters without any additional sign indicate scalar quantities:

$$\dot{F}_0 = \frac{K\,dsds_1}{r^3}\,\dot{I}_1 \times (\dot{r} \times \dot{I}) \qquad (1)$$

where K is a constant depending upon the physical nature of the medium interposed between 2 elements.

From vector analysis, it is known that the vector $(\dot{r} \times \dot{I})$, when used in cross multiplication, is equal to the anti-self-conjugate dyadic $(\dot{I}\dot{r} - \dot{r}\dot{I})$ in direct multiplication, used as a prefactor or post-factor, depending on whether $(\dot{r} \times \dot{I})$ is used as a prefactor or post-factor. The expression (1) of the force $\dot{F}_0$ may, therefore, be rewritten as follows:

$$\dot{F}_0 = \frac{K\,dsds_1}{r^3}\,\dot{I}_1 \cdot (\dot{I}\dot{r} - \dot{r}\dot{I}) \qquad (2)$$

That is, the electromagnetic force exerted on an element ds_1 of a conductor carrying the current $\dot{I}_1$, by the element ds of a second conductor carrying the current $\dot{I}$, is proportional to the direct product of the current vector $\dot{I}_1$ into the anti-self-conjugate dyadic $(\dot{I}\dot{r} - \dot{r}\dot{I})$. It will be recalled now, and it is apparent from equation 2 that the direct product of a vector by an anti-self-conjugate dyadic lies in the plane common to the antecedents and consequents of the dyadic. It will be recalled also (or it may be proved directly by expanding the dot product $\dot{F}_0 \cdot \dot{I}_1 = \frac{Kdsdsr}{r^3}\,\dot{I}_1 \cdot (\dot{I}\dot{r} - \dot{r}\dot{I}) \cdot \dot{I}_1 = 0$) that the direct product of a vector by an anti-self-conjugate dyadic is perpendicular to the vector. Once these 2 rules are recalled, the space position of the force $\dot{F}_0$ is immediately visualized from equation 2. $\dot{F}_0$ lies in the plane of $\dot{r}$ and $\dot{I}$ and is perpendicular to $\dot{I}_1$. From (2), the 2 components of the force $\dot{F}_0$ along $\dot{r}$ and $\dot{I}$ may also be readily computed respectively at:

$$\frac{Kdsds_1}{r^3}\,(\dot{I}_1 \cdot \dot{I})\dot{r} \quad \text{and} \quad \frac{Kdsds_1}{r^3}\,(\dot{I}_1 \cdot \dot{r})\dot{I} \qquad (3)$$

Furthermore the 3 space vector $\dot{I}$, $\dot{I}_1$, $\dot{r}$ may be expressed in terms of any arbitrarily chosen orthogonal system ijk as follows:

$$\dot{I} = xi + yj + zk$$
$$\dot{I}_1 = x_1 i + y_1 j + z_1 k$$
$$\dot{r} = r_1 i + r_2 j + r_2 k$$

Correspondingly the dyadic $(\dot{I}\dot{r} - \dot{r}\dot{I})$ in nonion form becomes:

$$(\dot{I}\dot{r} - \dot{r}\dot{I}) = (r_2 x - r_1 y)(ij - ji) + (r_3 x - r_1 z)(ik - ki) + (r_3 y - r_2 z)(jk - kj)$$

From which:

$$\dot{F}_0 = \frac{Kdsds_1}{\sqrt{r_1^2 + r_2^2 + r_3^2}} \times \left[\{y_1(r_1 y - r_2 x) + z_1(r_1 z - r_3 x)\}\,i + \{x_1(r_2 x - r_1 y) + z_1(r_2 z - r_3 y)\}\,j + \{x_1(r_3 x - r_1 z) + y_1(r_3 y - r_3 z)\}\,k\right] \qquad (4)$$

By means of either (3) or (4), the electromagnetic force between 2 elements of conductors carrying currents may be calculated. In the practical applications, if the expressions (3) are used, the vectors $\dot{I}$, $\dot{I}_1$, $\dot{r}$ may be decomposed in such a manner, or if using equations 4, the systems ijk may be so chosen as to reduce the necessary calculations to a minimum.

The forces on finite lengths of conductors are calculated by means of appropriate integrations.

Of course the same conclusions may be reached, without much difficulty, from equation 1 by expanding the triple vector product according to the rules of vector analysis, without any knowledge of dyadics.

K. L. Wildes (Massachusetts Institute of Technology, Cambridge): The authors of this group of papers have shown remarkable genius in the application of 2 closely related branches of mathematics to electric-circuit problems. The method of Sah is limited to 3-phase, or 3-branch circuits, since it is based upon the 3-dimensional vector analysis of Gibbs. I am inclined to agree with Sah, however, that the better initial approach to the whole subject of "higher circuit analysis" is through the vector algebra rather than the tensor algebra.

During the term just closing at MIT I have been presenting, as a part of one of my graduate courses in electric power-circuit theory, this vector algebra method of solving 3-phase unbalanced circuits. From this experience it is my opinion that the best pedagogical approach to this whole matter is, first, to study thoroughly the elements of vector algebra and linear vector functions, as developed by Gibbs and Wilson. This would be followed by a study of Sah's first paper in which the application is made to instantaneous 3-phase voltages or currents as phase components of a 3-dimensional vector. This paper also develops the simpler operations with impedance and admittance dyadics. Then, just as we usually go from the study of instantaneous values of alternating quantities to the complex representation, we proceed to Sah's second paper, in which we find the vector method applied to currents and voltages in the complex form. This transition is not difficult because the differences between vectors whose components are instantaneous values and those whose values are complex are practically the same differences as those which exist between single-phase quantities.

The final, and perhaps the most difficult step in the application of this method to the solution of circuits, is the development of the technique of solving equations once they are written. This technique involves great ingenuity, as well as a great deal of experience in handling vector equations. Many of these applications and ingenious methods of solving vector equations have been worked out by Sah, and it is my hope that these will soon be made available in future papers, or preferably in the form of a book.

Since this method is a direct competitor of the method of symmetrical components in solving unbalanced 3-phase circuits, it may be in order to make a comparison of these 2 methods. It has been our experience that circuits involving balanced impedances, except at a single point, or

possibly 2 points of unbalance, are more easily solved by the method of symmetrical components, while circuits possessing impedances of considerable unbalance are probably solved with about the same ease by the new method as with symmetrical components. There is probably some degree of complexity at which the vector method of solution becomes easier than the component method. This is especially true if some systematic, or perhaps mechanical method, of aiding the solution to the equations can be developed. The technique of understanding and using the method of symmetrical components is certainly much simpler than the new method, and would be, I should say, a prerequisite to studying it. For example, in the paper dealing with complex vectors the zero-sequence, positive-sequence, and negative-sequence components of a vector representing a set of voltages are found by dotting this vector with the isoclinic or zero-sequence vector u, the positive-sequence vector f and the negative-sequence vector b, respectively. In our class work we have duplicated the symmetrical-component solutions of circuits with impedances unbalanced at one point in terms of the new vector *notation* simply to become acquainted with this notation. We have then proceeded to solve the same problems by not only a notation, but a *process*, which characterizes Sah's work.

A careful study of this vector method not only has merits of its own, but forms an excellent foundation for the understanding of tensor algebra which is the subject of the papers by Kron, Boyajian, and Bewley.

In conclusion, I cannot refrain from saying that I have great admiration for the fundamental development of these methods of analysis by Sah and Kron. The time for evaluating their contribution has not yet arrived, but it is the responsibility of the electrical engineers and the professors of electrical engineering in the colleges to give attention to these methods and to come to a sound evaluation of their utility within the next 2 or 3 years. Not until many problems have been worked out to final numerical results can we say definitely whether the new methods are capable of organizing and clarifying large classes of problems, or whether, in general, the use of these methods makes the problems more obscure and more difficult of solution. I am personally enough interested to attempt to find the answer to this question.

Joseph Slepian (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The 2 papers by Sah are to be commended for the interesting material they present, and the temperate tone used by the author in estimating the value of his results. In all cases, the arbitrary character of certain assumptions are plainly stated. The definition of a scalar as having magnitude but no direction, and a vector as having magnitude and direction is in agreement with all previous usage. If any fault is to be found, it is that the mathematical terminology is a form which seems to be passing out of use. The dyadics of Gibbs are perhaps in the same class as the quaternions of Hamilton, namely, seldom used in modern mathematical works. It is an interesting evidence of the rapidity of progress in mathematics that the reference book, used by Sah, reference 1 in his first paper, is only 12 years old.

The first section describing "Three Phase Impedance as an Entity" makes it quite clear, by leaving out all irrelevant notions, that the impedance may be regarded as an entity, with 9 components in the 3-phase case, without requiring it to be a tensor, dyadic, or anything other than a set of numbers describing an electrical system.

The next section introduces the dyadic notation with the pairs of unit vectors occurring as symbols. Strangely enough, these double unit vector symbols occur nowhere else in the paper. I think this is the best evidence of their unnecessary and irrelevant quality.

As Sah states, the geometrical representation which he gives to a 3-phase set of currents or voltages, namely, an ellipse with center at a fixed origin, and a specified initial point on the ellipse, is in a certain sense arbitrary. But so too is the geometrical representation of a single aternating quantity as a vector in a plane. But in this latter case, all the arithmetic calculations we make with single-phase quantities correspond to simple geometric operations upon their corresponding vectors. Thus the addition of 2 single-phase quantities corresponds directly to the vector addition of their corresponding vectors. It is these correspondences which make the vector representation of single-phase quantities so valuable.

But unfortunately, not quite so good a case can be made out for Sah's ellipse representation of 3-phase quantities. The ellipse corresponding to the sum of 2 sets of 3-phase quantities is not related in any so obvious or suggestive a manner to the ellipses corresponding to the individual sets of 3-phase quantities. However, certain calculations, made with 3-phase quantities do have simple, geometrical equivalents in Sah's representation. The 3 symmetrical components are represented by 2 circles and a line which have very simple relationships to the ellipse as Sah shows. Similarly, changing from delta to wye components or vice versa, corresponds to simple operations upon the representative ellipse.

In his second paper, Sah generalizes from the notion of a vector with real components to that of a vector with complex components, and shows well the value of these ideas in application to 3-phase alternating quantities. The mathematics is all good and valid. It seems to me, however, that it might be put into more attractive form by generalizing from the real space to the "unitary" space with complex components, now used so extensively in quantum mechanics.

In vector analysis in real Euclidean space, a fundamental scalar is the product of two vectors defined as

$$X \cdot Y = x_1 y_1 + x_2 y_2 + x_3 y_3$$

with obvious significance to the notation. This expression must be generalized to meet the case where x_1, x_2, x_3, y_1, y_2, y_3, may be complex numbers instead of only real numbers. Now it is not necessary in making the generalization, to use precisely the same formula as for the case of reals, but it is sufficient, to use a formula for the case of complex components which will reduce to the above formula when the components become real. Thus we may define for the scalar product, instead of the above expression, which Sah uses, the following:

$$X \cdot Y = x_1^* y_1 + x_2^* y_2 + x_3^* y_3$$

where x_1^*, x_2^*, x_3^* are the conjugates of x_1, x_2, x_3. Obviously when x_1, x_2, x_3 are real this expression reduces to the preceding one.

The definition of the scalar product in this way, by a Hermitian instead of a quadratic form, has many advantages. By this definition, the scalar product of a vector by itself is the square of its length or magnitude as Sah defines it, and is never negative, and is zero only when all the components of the vector are zero. If we call 2 vectors mutually perpendicular when their scalar product thus defined is zero, then no vector is perpendicular to itself. In 3-dimensional complex space a set of no more than 3 mutually perpendicular unit vectors can be found. If I, J, K, are any 3 such mutually perpendicular unit vectors, and if X is any vector, then $X = (I \cdot X)\, I + (J \cdot X)\, J + (K \cdot X) K$ if this definition of scalar product is used.

Vector space with complex components and with this definition of the scalar product is much used in quantum mechanics. It is called unitary space, and has many properties similar to those of Euclidean space. A good account of unitary space is given in Weyl's "Group Theory and Quantum Mechanics."

With this definition of scalar product, the unit vectors u, f, b in Sah's paper, which represent unit symmetrical components (divided by $\sqrt{3}$) become mutually perpendicular. The transformation to symmetrical components becomes a "unitary" transformation which may be regarded as a generalization of the "orthogonal" transformation in real space, that is a rigid rotation of orthogonal axes.

Irven Travis (University of Pennsylvania, Philadelphia): The statements in this discussion are restricted to *linear* networks. In such networks the calculation of the currents resolves itself into the calculation of the values of the I's in a set of equations of the form

$$\left.\begin{aligned} Z_{11}I_1 + Z_{12}I_2 + \dots + Z_{1n}I_n &= V_1 \\ Z_{n1}I_1 + Z_{n2}I_2 + \dots + Z_{nn}I_n &= V_n \end{aligned}\right\} \qquad (1)$$

Methods of evaluating the Z's in a particular problem are well known. If the calculation of the I's is to be rendered simpler than seems to be indicated by these equations some scheme must be devised to circumvent the indicated algebraic work. Any such scheme, however, must ultimately express the I's in terms of the V's; or at least certain known functions of the I's in terms of certain known functions of the V's. Methods for accomplishing this have been variously described as vector, tensor, dyadic, matrix, etc, methods. It seems that the success of any of these schemes for simplification must depend upon special properties of the array

$$\left.\begin{matrix} Z_{11}Z_{12} \dots Z_{1n} \\ Z_{n1}Z_{n2} \dots Z_{nn} \end{matrix}\right\} \qquad (2)$$

(Conventional bars are not placed on this array nor is any name assigned to it lest

the writer's position be prejudiced.)

If the array (2) has special properties, as for example symmetry, *any* system designed to take advantage of these properties will meet with success. It the array has no special properties the various schemes suggested amount to statements of the same problem in terms of different notations and no particular advantage accrues to any one.

In January 1933, it was suggested to the writer by Carl Chambers, then a graduate student at the Moore School, that the Stokvis-Fortescue transformation could be expressed in matrix form more simply than in terms of the "sequence operators" used in Fortescue's 1918 paper. A matrix formulation for 3-phase circuits was developed, in which the matrix

$$\frac{1}{3}\begin{Vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{Vmatrix} \qquad (3)$$

and its inverse

$$\begin{Vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{Vmatrix} \qquad (4)$$

play an important part. After having been used in mimeographed form in the senior machinery course at the Moore School for 3 years this method of presenting symmetrical components was included in section 3 of the "Electrical Engineer's Handbook," Pender-DelMar, John Wiley and Sons, 1936. I was very much interested in Sah's paper as several of his expressions from the vector viewpoint are in complete agreement with similar expressions obtained from the matrix viewpoint.

However, neither the vector nor the matrix presentation has any virtue other than neatness of notation and clarity of expression. Any simplification in actual calculation of any given problem must be due to symmetry in the impedance matrix of the system. If there is no symmetry there can be no simplification.

From a pedagogical view point it is highly desirable to use some scheme which systematizes an analysis and correlates all calculations of a given class. Special cases are given added clarity if they appear as special cases of a general formulation rather than as isolated and unrelated problems. It is in this aspect and not in reduction in actual labor of calculation that tensors and matrices are of value in electrical engineering.

C. E. Rose (Federal Emergency Administration of Public Works, Washington, D. C.): Believing that the following discussion of the article, entitled, "Dyadic Algebra Applied to 3-Phase Circuits," by A. Pen-Tung Sah, which appeared in the August issue of ELECTRICAL ENGINEERING, may be helpful to others interested in the applications of dyadics and tensors to the solution of electrical problems, I submit the following:

A dyad is nothing more or less than the product of 2 vectors written as AB, and the symbolic sum of a number of dyads is a dyadic.

A matrix is a system of related but independent quantities whereas a determinant is either a real or complex number, or zero.

Therefore equation 28*d*, page 881 in this article is presented incorrectly, due probably to a typographical error. It is written as:

$$(\sqrt{3}u \times Z_m)_{2s} = j\begin{Vmatrix} -2.20 & -3.42 \\ 7.90 & 2.12 \end{Vmatrix} + j\begin{Vmatrix} 2.12 & 1.46 \\ 1.30 & 0.08 \end{Vmatrix} + j\begin{Vmatrix} -2.20 & -1.54 \\ -5.70 & 0.08 \end{Vmatrix}$$

the right-hand side of which is expressed as the sum of 3 dyadics of rank 2, whereas it should have been written as:

$$(\sqrt{3}u \times Z_m)_{2s} = \begin{vmatrix} -2.20 & -3.42 \\ 7.90 & 2.12 \end{vmatrix} + \begin{vmatrix} 2.12 & 1.46 \\ 1.30 & 0.08 \end{vmatrix} + \begin{vmatrix} -2.20 & -1.54 \\ -5.70 & 0.08 \end{vmatrix} = -11.66$$

because it is the sum of 3 determinants of rank 2, and involves neither a matrix nor a dyadic and is numeric only.

Again, equation 19, page 880, is written as:

$$Y = \begin{Vmatrix} y_{aa} & y_{ab} & y_{ac} \\ y_{ba} & y_{bb} & y_{bc} \\ y_{ca} & y_{cb} & y_{cc} \end{Vmatrix} = Z^{-1} = \frac{1}{D}\begin{Vmatrix} (z_{bb}z_{cc} - z_{bc}z_{cb}) \ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots (z_{aa}z_{bb} - z_{bb}z_{ba}) \end{Vmatrix}$$

It is not necessary when writing a tensor equation, which contains only electric tensors, to define the voltages under consideration, as covariant tensors which they are, but when once a convention has been established as it is in this article by equation 1, page 876, which is written as:

$e_a = z_{aa}i_a + z_{ab}i_b + z_{ac}a_{ac}i_c$, etc.

and which properly defines the voltages as a covariant tensor of rank 1, and the impedances as a covariant of rank 2, then it is thought that the admittance Y would be better defined as a contravariant tensor of rank 2, because this corresponds to reality in which case we would write:

$$Y = \begin{Vmatrix} y^{aa} \ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots y^{cc} \end{Vmatrix} = Z^{-1}$$

The matrix Z^{-1}, which is the inverse of matrix Y is obtained from it by replacing each element of the Y-matrix by its cofactor, with the superscrips changed to subscrips and permuted once, divided by the determinant of the Y-matrix because

$y^{ik} = Z_{ki}^{-1}$

namely it is a skew-symmetric tensor, and is nothing more than the vector product of 2 generalized vectors. Thus if we write vectorially:

Vector A times vector $B = A \cdot B + A + B$, the last term is really a skew-symmetric tensor of rank 2, which is written in tensor form as:

$A_{ik} = A_{ki}$

The simplest matrix which we encounter is the co-ordinate of a point in 2-dimensional space as (X, Y).

The "scalar of the second" used in this article is simply

$\phi_2 = (\phi_s)_2 = A_{11} + A_{22} + A_{33}$

in which $A_{11} \ldots A_{33}$ are the elements of the principal diagonal of the inverse for the matrix under consideration. The matrix:

$$\begin{Vmatrix} 0 & -1 & 1 \\ 1 & 0 & -1 \\ -1 & 1 & 0 \end{Vmatrix}$$

which appears several times in this article is nothing more or less than:

$$\begin{Vmatrix} ii & ij & ik \\ ji & jj & jk \\ ki & kj & kk \end{Vmatrix}$$

obtained by combining the 3 unit vectors, 2 at a time, into dyads multiplied by -1.

Professor Gibbs, part of whose theorems A. Pen-Tung Sah employed, proved that a dyadic ϕ possessed 3 scalar invariants; namely

$\phi_1 = a_{11} + a_{22} + a_{33}$
$\phi_2 = A_{11} + A_{22} + A_{33}$

$$\phi = \begin{Vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{Vmatrix}$$

A transpose is a dyadic, or matrix, which is obtained by interchanging rows and columns. The simplest definition of a tensor is, I believe; that if the 9 quantities:

$$\begin{Vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{Vmatrix}$$

possess the property that when written as

$\sum_{ik} a_{ik}a_ib_k = a_{11}a_1b_1 + a_{21}a_1b_2 + a_{13}a_1b_3 \ldots$

is invariant to any arbitrary rotation of the Cartesian co-ordinate system, wherein A and B are any arbitrarily chosen vectors, then this last matrix presented above is a tensor. This definition also yields a simple method to test for the existence of a tensor by subjecting it to a rotation and if, after simplifications, it returns to the identical original form we know that it is a tensor.

An Analysis of the Shaded-Pole Motor

Discussion and author's closure of a paper by P. H. Trickey published in the September 1936 issue, pages 1007–14, and presented for oral discussion at the induction machinery session of the winter convention, New York, N. Y., January 27, 1937.

Selby Haar (Board of Transportation, City of New York, N. Y.): Emphasis has been laid on the small rating of the usual shaded-pole motor. Have you ever observed with these motors that the current at fractional loads is less than at no load?

G. G. Veinott (Westinghouse Electric & Manufacturing Company, Springfield, Mass.): Trickey has presented an illuminating analysis of a type of motor of great commercial importance, and his analysis is probably the first of its kind ever presented before AIEE on this important

motor. The "shading principle," that is the action of a short-circuited coil placed around a portion or all of a magnetic circuit, is a familiar one; it is used in damper or amortisseur windings of synchronous machines, it is used in watt-hour meters, a-c contactors and in many other places.

Once when studying damper windings, I discovered some fundamental equations of the damped magnetic circuit which were most helpful quantitatively and qualitatively. So far as I know, these equations and concepts are original and I am now publishing them for the first time because of the light they throw upon the principle of the shading coil.

The conventional method for analyzing a damped magnetic circuit is to compute the current induced in the damping coil by the changing flux and subtract the magnetomotive force due to this current from the primary-exciting magnetomotive force, obtaining a resultant magnetomotive force; from this resultant magnetomotive force is calculated the flux, which in the case of an a-c supply, is assumed to be proportional to and in phase with this resultant magnetomotive force.

A-c circuits containing resistance and inductance could be solved in an analogous manner by computing the voltage induced in the inductance, subtracting it from the impressed voltage, obtaining a resultant voltage; the current would then be proportional to, and in phase with this resultant voltage. It has been found more convenient to analyze such circuits by introducing the concent of reactance, which might be termed a "quadrature resistance." The method of analyzing a damped magnetic circuit which I am about to outline is exactly analogous to the conventional method of treating a-c circuits; in it I introduce a concept of what might be termed "quadrature reluctance" since, in the magnetic circuit, it bears the same relation to reluctance that inductive reactance does to resistance in an electrical circuit.

The fundamental equation for the instantaneous value of flux in a magnetic circuit of reluctance $\mathcal{R}$ excited by a sinewave magnetomotive force, $m = M_m \sin \omega t$, and interlinked by an electrical circuit of N turns having an ohmic resistance of r ohms and no leakage inductance, can be shown to be

$$m = \phi\mathcal{R} + \frac{4\pi n^2}{r \cdot 10^9}\frac{d\phi}{dt} = M_m \sin \omega t \tag{1}$$

Now let,

$$\frac{4\pi n^2}{r \cdot 10^9} = \mathcal{L} \tag{2}$$

Then equation 1 becomes

$$m = \phi\mathcal{R} + \mathcal{L}\frac{d\phi}{dt} = M_m \sin \omega t \tag{3}$$

The fundamental equation of an a-c circuit containing resistance and self-inductance is

$$e = Ri + L\frac{di}{dt} = E_m \sin \omega t \tag{4}$$

Equations 3 and 4 are seen to be identical in mathematical form. Since these differential equations are identical in form, the solutions must also be identical in form and therefore, we may write at once (or solve equation 3 if we wish)

$$\phi = C\epsilon^{-\frac{\mathcal{R}}{\mathcal{L}}t} + \frac{M_m}{\sqrt{\mathcal{R}^2 + (\omega\mathcal{L})^2}}\sin(\omega t - \theta) \tag{5}$$

or, neglecting the transient term, the root-mean-square value of flux is

$$\Phi = \frac{M}{\sqrt{\mathcal{R}^2 + (\omega\mathcal{L})^2}} \tag{6}$$

and the flux Φ lags behind the exciting magnetomotive force by an angle

$$\theta = \cos^{-1}\frac{\mathcal{R}}{\sqrt{\mathcal{R}^2 + (\omega\mathcal{L})^2}} \tag{7}$$

Thus, it can be seen that a damper coil affects a magnetic circuit the same way self-inductance affects an electric circuit, even so far as transient effects are concerned. That is to say, in a-c magnetic circuit, a damper or shading coil reduces the effective a-c component of flux and causes this flux to lag behind the exciting magnetomotive force.

Nearly all elementary text books refer to the Ohm's law of the magnetic circuit. Likewise, all a-c textbooks extend the Ohm's law of the d-c circuit to the a-c circuit by using a "quadrature resistance" or reactance in combination with resistance. None of them, apparently, extend the "Ohm's law of the magnetic circuit" to damped magnetic circuits excited by alternating current. I would propose to do so by introducing a few new terms which I list below; those terms in *italics* are of my own invention.

Thus, the angle of lag of the flux in a shading coil, behind the flux in the unshaded portion is

$$\theta = \cos^{-1}\frac{\mathcal{R}}{\sqrt{\mathcal{R}^2 + (\omega\mathcal{L})^2}} \tag{7}$$

$$= \cos^{-1}\frac{\mathcal{R}}{\sqrt{\mathcal{R}^2 + \left(\frac{8\pi^2 n^2 f}{r \cdot 10^9}\right)^2}} \tag{8}$$

Moreover, in a damped magnetic circuit, the ratio of the damped flux, to that which would exist with no damping is given by the equation

$$\cos\theta = \frac{\mathcal{R}}{\sqrt{\mathcal{R}^2 + (\omega\mathcal{L})^2}} \tag{9}$$

Equation 9 might be called the damping factor.

The foregoing analysis has been given because of the light it throws on the principle of the shading coil. It does not contradict any point of Trickey's analysis but will, I hope, help to explain how a shading coil reduces the flux and causes it to lag behind its magnetomotive force producing in effect a sort of makeshift rotating field in a shaded pole motor.

It is to be noted that this method of analysis automatically eliminates one variable, namely, the current in the shading coil. Perhaps, by using this concept, Trickey could reduce his analysis to 3 simultaneous equations, instead of 4 as he now has. This is merely offered as a suggestion which may or may not be of value.

Trickey has compared the performance of the shaded pole motor with the split-phase motor with no starting switch. In the light of the foregoing analysis, an interesting comparison can be made between these types of motors. In both types there are 2 magnetic fields set up approximately 90 degrees apart in space. In both motors these fields are displaced slightly in time. In both motors these fields are each set up as a result of the same single-phase electromotive force. In both types of motors, it may be said, there are 2 magnetic circuits. But herein lies the difference: in the split-phase motor there are 2 magnetomotive forces displaced in time phase from each other acting on similar magnetic circuits, so the fluxes are displaced by the same phase angle as the magnetomotive forces; in the shaded-pole motor there is only one magnetomotive force acting upon 2 magnetic circuits in parallel and the phase displacement in fluxes is due to dissimilarity in the magnetic circuits. Thus, it is scarcely to be wondered that the performance of the 2 types of motors should be similar.

P. H. Trickey: It is quite possible for a shaded-pole motor to have less input under load than at no load. In fact, the losses of shaded-pole motors very often decrease with load. If the motor is highly saturated, this will sometimes result in an actual decrease in watts input in going from no load to full load.

Veinott's discussion is very interesting, and it seems to me to have possibilities in handling the difficulties of shaded pole circuits. In this case of the shaded pole motor, if it will result in the reduction in the number of variables from 4 to 3 even at the expense of adding another constant or two, it will probably make possible a much more satisfactory solution.

Electric Circuit		Magnetic Circuit	
Electromotive force	E	Magnetomotive force	M
Current	I	Flux	Φ
Resistance	R	Reluctance	$\mathcal{R}$
Inductance	L	*Delayance*	$\mathcal{L}$ see equation 2
Reactance	$X = 2\pi fL$	*Retardance*	$x = 2\pi f\mathcal{L}$
Impedance	$R + jX$ or $\sqrt{R^2 + X^2}$	*Hindrance*	$\mathcal{R} + jx$ or $\sqrt{\mathcal{R}^2 + x^2}$
Conductance	$\left(G = \frac{R}{R^2 + X^2}\right)$	Permanence	$\left(\mathcal{P} = \frac{\mathcal{R}}{\mathcal{R}^2 + x^2}\right)$
Susceptance	$B = \frac{X}{R^2 + X^2}$	*Accordance*	$\left(\mathcal{B} = \frac{x}{\mathcal{R}^2 + x^2}\right)$
Admittance	$Y = G - jB$	*Acceptance*	$(y = \mathcal{P} - j\mathcal{B})$

The Tensor—A New Engineering Tool

August 1936 issue, pages 856–62

Tensor Algebra in Transformer Circuits

November 1936 issue, pages 1214–19

Tensor Analysis of Multielectrode-Tube Circuits

November 1936 issue, pages 1220–42

Discussion of papers by A. Boyajian, L. V. Bewley, and Gabriel Kron published in the August 1936 and November 1936 issues and presented for oral discussion at the tensor analysis session of the winter convention, New York, N. Y., January 26, 1937.

W. E. Byrne (nonmember; Virginia Military Institute, Lexington): One of the best ways in which to find out what is contained in a newly organized theory is to teach the material. During the first term of this school year I have given a course one hour a week on vector analysis, polyadics, matrices and tensors to a small group of students and instructors. As an application of these mathematical topics I took up the first 2 papers of Kron (*General Electric Review*, 1935). Naturally such applications are not as general as the basic mathematical theory since the connection matrices are specialized, in that the elements are merely -1, $+1$, and 0. Kron and others working in this field are to be commended for developing such powerful and general methods of attacking problems of electrical engineering. It is interesting to note that engineers and mathematicians promise to have more and more in common in the future.

M. G. Malti (Cornell University, Ithaca, N. Y.): If we look back to the early records of the use of the algebra of complex numbers in connection with electrical-engineering problems we would find that the problems of those days (early twentieth and late nineteenth century) are just as readily solvable with as without the use of complex numbers. The introduction of complex numbers into engineering paved the way for a deeper, more comprehensive and more forceful analysis of these and later problems.

I shall go a step further and state that most of the early problems were too simple to require more than the mere algebra of complex numbers. The application of the theory of functions of complex variables to electrical-engineering problems was unheard of in those days. Now, within the life span of those who witnessed the first introduction of the algebra of complex numbers, we see a rather common use of the theory of fuctions of complex variables in connection with operational analysis, Laplace and Fourier Transforms, etc.

There was little sympathy and no understanding shown to those select few who used the albegra of complex numbers in the early days. Little sympathy is shown now to those who talk of Laplace transforms and contour integration and downright opposition to those who dare mention tensors.

It is undoubtedly true that our present engineering problems do not call for tensor analysis. But who can predict that the engineers of the future will not need tensor analysis to solve their problems? Any engineer who 30 years ago dared make the statement that engineers would have to become thoroughly acquainted with mathematical works on functions of complex variables to solve their knotty theoretical problems of network analysis would have been laughed at. But here we are today using these works most effectively in circuit analysis.

I make these statements more to express a point of view than to support one faction or another. We all agree that it is impossible to guess what the problems of the future will be and what type of analysis these problems will require. Hence it behooves us to view with sympathy and understanding all work of an advanced nature in the hope that, if it is not immediately useful, it might prove to be so in the future.

M. F. Gardner (Massachusetts Institute of Technology, Cambridge): The linear algebraic transformation expressing the element currents $i^k(t)$ in terms of the loop currents $\hat{\imath}^\alpha(t)$ in a connected network is

$$i^k(t) = C_\alpha{}^k \hat{\imath}^\alpha(t) \tag{1}$$

in which $C_\alpha{}^k$ is the connection matrix, and in which the k and α run over the elements and loops, respectively.

The linear equations expressing the envarience of the total instantaneous power $p(t)$ under transformation from element variables $[i^k(t)$ and $v_k(t)]$ to loop variables $[\hat{\imath}^\alpha(t)$ and $\bar{v}_\alpha(t)]$ is

$$p(t) = v_k(t)i^k(t) = v_\alpha(t)\hat{\imath}^\alpha(t) \tag{2}$$

If the voltages and currents are sinusoidal—and only steadystate relations are of interest— the i's of equation 1 can be replaced by their complex amplitudes. With the i's of (2) replaced by their complex amplitudes, the v's must be replaced by the conjugates of their complex amplitudes. The p is then replaced by the so-called "vector power." This use of conjugate complex amplitudes works satisfactorily for this particular case—the steady state with sinusoidal functions or sums of sinusoidal functions.

Barnes (of Tufts College) and I have noted that the use of conjugate complex amplitudes in this way does not carry over to the case of transients, which involve nonperiodic functions. Since we have not seen a satisfactory statement in the literature of a generalization to cover such cases, we shall indicate one here.

Before we can state the essential idea of this extension it perhaps will be helpful to make a few preliminary remarks about the Laplace transformation (hereafter abbreviated L-transformation) by which the extension will be made.

Let $s = \sigma + j\omega$ be a complex variable corresponding to the real variable t. Then a general time function $f(t)$ can be transformed into its corresponding generalized frequency function $F(s)$ if $f(t)$ is given and is such that the following definite integral is absolutely convergent,

$$\int_0^\infty f(t)e^{-st}dt = F(s) \qquad c_a < \Re(s) \tag{3}$$

This integral defines $F(s)$ for that part of the complex s-plane wherein the real part of s is sufficiently great to insure the integral having a finite value.

If, on the other hand, $F(s)$ is the function known and the corresponding $f(t)$ is unknown, (3) becomes an integral equation, but its solution is given by the integral

$$\frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} F(s)e^{ts}ds = f(t) \quad 0 < t \quad c_a < c \tag{4}$$

This is a line integral in the complex plane. The path of integration is a straight line paralleling the axis of imaginaries and lying in that part of the s-plane in which $F(s)$ is defined.

The integrals of (3) and (4) constitute, respectively, the direct L-transformation and its inverse. Further, an $f(t)$ and its $F(s)$ constitute an L-transform pair and can be written as

$$f(t) \qquad\qquad F(s) \tag{5}$$

For application of these ideas in the present discussion it is necessary to know that, given 2 L-transform pairs

$$\left.\begin{matrix} f_1(t) & \qquad F_1(s) \\ f_2(t) & \qquad F_2(s) \end{matrix}\right\} \tag{6}$$

the pair which results when the 2 *time* functions are multiplied is

$$f_1(t)\,f_2(t) \quad \frac{1}{2\pi j}\int_{c_1-j\infty}^{c_1+j\infty} F_1(w)F_2(s-w)dw \qquad \left.\begin{matrix} c_{a_1} < c_1 \\ c_{a_2} < \Re(s-w \end{matrix}\right\} \tag{7}$$

For interpretation of this it is helpful to have also the pair which results when the 2 *frequency* functions are multiplied. This pair is commonly found in engineering literature. It is

$$\int_0^t f_1(\tau)f_2(t-\tau)d\tau \qquad F_1(s)\,F_2(s) \tag{8}$$

Pairs (7) and (8) can be abbreviated by introducing the notation

$$f_1(t)\,f_2(t) \qquad F_1(s) * F_2(s) \tag{7a}$$

$$f_1(t) * f_2(t) \qquad F_1(s)\,F_2(s) \tag{8a}$$

In (7) the integration in the complex w-plane is along a straight line paralleling the axis of imaginaries and lying in that part of the w-plane in which $F_1(w)$ is defined. In (8) the integration is along the positive time axis. In both integrals the functions are said to be convolved. In (8) the f_2 function is "folded" before multiplication by the f_1 function. In (7) the F_2 function is rotated by 180 degrees and shifted by the amount s before multiplication by the F_1 function. Various forms of the convolution integral for functions of real variables shown in (8) are referred to in the engineering literature as Borel's integral, Duhamel's integral, and the superposition integral. For frequency functions, the counterpart of this superposition-type in-

tegral is the complex convolution integral appearing in (7).

Applying these ideas now to the original equations 1 and 2, each member is transformed by use of (3), i.e., each member is multiplied by the exponential e^{-st} and integrated from 0 to ∞. Equation 1 transforms to

$$I^k(s) = C_\alpha{}^k I^\alpha(s) \quad (9)$$

Equation 2 presents cases of time-function products. In their transformation (7*a*) is used. The result is

$$P(s) = V_k(s) \quad I^k(s) = v_\alpha(s) * I^\alpha(s) \quad (10)$$

Each typical term in (9) and (10)—instead of being a function of t as in (1) and (2)—is a function of s. The currents, voltages, and power involved may be any functions of time, provided only that they are L-transformable by (3). When it is necessary to return to functions of time, the inverse transformation (4) is used.

It should not be concluded from what has been said here that in practical work it is advisable, even though possible, to replace the simple operation of multiplication by the complicated operation of convolution (*). But in theoretical work it may be very convenient to make this replacement, especially when it is not necessary to actually carry out the indicated convolution.

Summarizing, for theoretical work utilizing tensor or matrix notation a scheme is provided for handling general time functions by means of their L-transforms much as sinusoidal functions are now treated by means of their complex amplitudes. The condition remaining which these time functions must fulfill is that they be L-transformable. In addition to furnishing a generality needed for theoretical work, the transform method provides a compact symbolism which fits conveniently into the tensor or matrix scheme of notation.

W. H. Ingram (nonmember; New York, N. Y.): On page 1220 the author mentions a "first generalization theorem" and says that by the use of the notation advocated the behavior of the most complex systems are "described" by the application of the theorem to equations of motion governing the simplest of all systems, namely, that of one degree of freedom.

This should be a theorem of great importance, as its statement and the italics used would suggest, but on examination it would appear to be merely a statement that from the equation $e = Zi$ governing a simple system we can deduce the equation $e_n = Z_{nm}i^m$ for a more complex system although, presumably, the fact that the ordinary equation

$$e_n = \Sigma Z_{nm} i_m$$

rests in some way on the simpler one is not claimed as requiring the new theorem.

If this is the generalization claimed, we are brought immediately to the question of what a tensor is and what bearing the concept of a tensor has on the solution of network, machine and vacuum-tube problems.

To begin with, a tensor has no meaning except in reference to, or conjunction with, *admissible co-ordinate systems*. Not all co-ordinates used by electrical engineers come under this head: the co-ordinates used by Blondel and Park, among others, in the theory of electrical machines, do not. To prove this, take, for example, the expression

$$ds^2 = g_{ij}dq^i dq^j$$

called the Riemannian *metric* in certain geometrical interpretations of dynamics and connected with the kinetic energy. The coefficient g_{ij} is a tensor because of the fact that

$$g_{ij} = g_{\alpha\beta}{}^* \frac{\partial q^\alpha}{\partial q^i} \frac{\partial q^\beta}{\partial q^j}$$

when the q's with Latin superscripts and those with Greek form 2 admissible co-ordinate systems. Given the first system, a second can always be obtained by a linear transformation, that is, of the form

$$q^i = b_j{}^i q^{*j}$$

as a matter of fact, an infinite number of admissible systems exist in this case.

However, in the theory of electrical machinery, transformations of the form

$$dq^i = \beta_\alpha{}^i dx^\alpha$$

occur where the dx's are the differentials of quasico-ordinates and where the right-hand side is a not completely integrable Pfaffian so called, that is, the right-hand side is not a complete differential. Substitute this last equation into the formula for the metric and we obtain

$$ds^2 = g_{\alpha\beta}{}^* dx^\alpha dx^\beta$$

so that

$$g_{ij} = g_{\alpha\beta}{}^* \frac{\partial \dot{x}^\alpha}{\partial \dot{q}^i} \frac{\partial \dot{x}^\beta}{\partial \dot{q}^j}$$

where $\dot{x}$ is the total derivative of x with respect to the time or any other parameter. This last expression is *not* in agreement with the rule for the transformation of a covariant tensor of the second order. Hence the x's, which include the co-ordinates introduced by Blondel and which are indispensable in the theory of electrical machinery, do *not* form an admissible co-ordinate system.

The functions $\beta_1{}^i, \beta_2{}^i \ldots \beta_n{}^i$ are regarded by geometers as the components of a covariant vector, in the manifold of the q's, tangent to a congruence of the curves defined by the equations

$$\frac{dq^1}{\beta_i{}^1} = \frac{dq^2}{\beta_i{}^2} = \ldots = \frac{dq^n}{\beta_i{}^n}$$

and the dx's, given by $dx^i = \alpha_j{}^i dq^j$, may be interpreted as the differential co-ordinates of a neighboring point in the associated space of the tangents mentioned and forming a Cartesian reference system. A different system of congruences chosen in the q-space gives a different associated space and this is also so in general when there is a metric defining the associated space.

In the present case the metric in question would be g^*, the x's referring to arcs of the congruences, and the associated space is Riemannian. But no tensor discussion involving this space is possible except when based upon the underlying q-system of co-ordinates. In other words, no tensors occur in, or can enter, the theory of any commutator machine until the latter is regarded as a transform of a slip-ring machine and then only with reference to the true co-ordinates involved.

When the commutator machine has fewer degrees of freedom, certain dx's are identically zero and the theory of non-holonomic metrical subspaces comes in. (Vranceanu, "Les espaces non-holonomes," Paris, 1936 page 18.)

The question has been suggested: can tensors enter the congruence space via the asymmetric "coefficients of affine connection" of ultra Riemannian geometry and, if so, has that fact any bearing on the theory of electrical machines and circuits? It is known (Eisenhart, "Non-Riemannian Geometry," page 14) that the paths of the manifold corresponding to geodesics of a Riemannian space are given by the curves defined by the equation

$$\dot{q}^j(\ddot{q}^i + \Gamma^i{}_{kl}\dot{q}^k\dot{q}^l) - \dot{q}^i(\ddot{q}^j + \Gamma^j{}_{kl}\dot{q}^k\dot{q}^l) = 0$$

where

$$2\Gamma^i{}_{jk} = L^i{}_{jk} + L^i{}_{kj}$$

provided $L^i{}_{jk}$ transforms according to the fundamental equation

$$\frac{\partial^2 q^i}{\partial \bar{q}^\alpha \partial \bar{q}^\beta} + L_{jk}{}^i \frac{\partial q^j}{\partial \bar{q}^\alpha} \frac{\partial q^k}{\partial \bar{q}^\beta} = \bar{L}_{\alpha\beta}{}^\gamma \frac{\partial q^i}{\partial \bar{q}^\gamma}$$

Now we cannot take

$$L^r{}_{jk} = g^{*rs}\Lambda_{jk,s}$$

as has been done (Kron, "Non-Riemannian Dynamics of Rotating Electrical Machinery," *Journal of Mathematics and Physics*, volume 13, 1934, page 156) for the x's would appear in place of the q's in this last equation and the existence of the derivatives $\partial x^i/\partial \bar{x}^\alpha$ cannot be established. A search for a more suitable "coefficient" might be in order if no metric were available, but in the theory of electrical machines and circuits a metric is always at hand and the geometry of the dynamics of electrical machinery and circuits is in fact ordinary Riemannian, as I have remarked elsewhere (*Bulletin* of the American Mathematical Society, September 1934, page 666). This, I gather, is also the opinion of Synge ("Tensorial Methods in Dynamics," University of Toronto Press, 1936).

The author calls $C_m{}^\alpha$ a "transformation tensor." The transformations involved are of such a special kind that the name used may be misleading. Consider the system of seven variables $x_1, x_2 \ldots x_7$ upon which 2 conditions are imposed, say the conditions that the equations $x_1 - x_2 + x_3 - x_6 = 0$ and $x_2 - x_3 + x_4 - x_7 = 0$ be satisfied. We can solve these equations for 2 of the variables, say x_6 and x_7. The remaining variables may be thought of as the independent ones and we may wish to designate them by special letters, say $y_1, y_2 \ldots y_5$. Hence we may write $x_1 = y_1$, $x_2 = y_2$, $x_3 = y_3$, $x_4 = y_4$, $x_5 = y_5$, $x_6 = y_1 - y_2 + y_3$, $x_7 = y_2 - y_3 + y_4$. The matrix of this "transformation" (it will be noted that there is no inverse) happens to be the author's matrix (48) in this case. The original 7 x's could represent the currents in 7 parts of a net and the equations of condition could represent the application of Kirchhoff's law at 2 junction points: the y's would then represent the currents in

complete circuits. This and many related topics are adequately expounded by Quade ("Klassifikation der Schwingungsvorgaenge in gekoppelten Stromkreisen," Leipzig, 1933) in terms of matrices. Redundant constraints, detectable by the rank of the Jacobian involved, are treated in the same way.

The fact that there are many ways of eliminating 2 of the x's ordinarily would not be interpreted as bringing in as many admissible co-ordinate systems in the tensor sense particularly in the case where the x's are the differentials of quasico-ordinates. Tensors come in only when the co-ordinates in one admissible co-ordinate system are related one-to-one to those in another, when the functional relation between them is of class C^m (that is, having continuous partial derivatives up to and including the mth order, $m \geqslant 1$), and when the functional Jacobian is not equal to zero. If tensors really were being considered here, Quade's circuitization matrix would contain functions, that is, (48) would contain partial derivatives of one set of co-ordinates with respect to another admissible set instead of the 0's and 1's shown. The author's 2 paragraphs between equations 20 and 21 would appear to be therefore erroneous.

To sum up the discussion above as it bears on the question of tensors, the situation would seem to be that to date tensors have not been brought into the theory of electrical nets and machines. When this has been done, the question of their usefulness will be less difficult to settle.

Equations 41 and the discussion of figure 3 would appear to be new developments, but on close inspection the addition theorem given by (41) is found to be quite trivial because of the fact that both the circuitizing matrix C and the impedance matrix of (a) and (b), figure 3, have to be of the same order. One does not know how to write down either of these matrices for (b) unless the order of the impedance matrix of the system that is to be connected at g_2 and p_2 is known in advance.

In the paper by L. V. Bewley the author implies that his method C is dynamical but his use of the terms "ignoration," "constraint," and "canonical" seem to be at variance with the meanings of these expressions in classical dynamics. No co-ordinate is "ignorable" in dynamics when there is dissipation involved, a force polygon being closed implies no constraint and the canonical equations in dynamics are equations of motion in terms of the displacements and momenta as variables exclusively. The equation

$$e_k = z_{kl}i^l$$

or its equivalent, was called more appropriately the "generalized Ohm's Law" by Kennelly.

The author says that the "connection tensor" C_α^j expresses old currents "before interconnection" in terms of new currents "after interconnection." The false impression may be conveyed that there is a physical rearrangement of the net to correspond to the mathematics, or vice versa. Both the "old" currents and the "new" currents must refer to the same system arrangement: in the first case to where the variables are not independent and in the second case to where redundant variables have been eliminated by algebraic processes. The theory has been given matrix form by Quade and others and the above mentioned "connection tensor" appears to be nothing more than Quade's circuitizing matrix.

Given a system of circuit segments or meshes arranged in the form of a net, with or without inductive coupling, and specified by the kinetic energy, the potential energy, the Rayleighean dissipation and the external work functions, Quade ("Klassifikation der Schwingungsvorgaenge in gekoppelten Stromkreisen," Leipzig, 1933) has shown (a) how force equations free from Lagrangean multipliers can be obtained in a more fundamental manner than usual, (b) how the operational determinant or matrix of a system classifies it on the basis of the elementary divisors of the determinant, and (c) the significance of *representatives* of the classes in question, which are exhaustively studied. The author's first transformer circuit (windings in series), load-ratio control circuit, and forked auto-transformer circuit come under one or other of these classifications.

The author's procedure differs from Quade's in 2 minor respects: the use of equations of ampere-turn balance and the inclusion of the electromotive forces e_0, e_1, etc. Some of these electromotive forces are not truly external but are reactive (with one sign or another) which it is necessary to introduce together with the equations of ampere-turn balance when any of the mutual inductances are left out of the analysis. This procedure seems to be necessary when it is desired to take into account excitation losses (which the author does not do) but otherwise the method adopted by Quade would seem to be simpler. Quade's method of finding the external forces acting in the circuits, given those acting in the meshes, can hardly be improved upon for simplicity (cf. ibid. ¶18).

As the author's discussion is really one in terms of matrices it is not clear how tensors come in at all. The use of tensor notation is one thing, to have a tensor enter is another. Bôcher used vector notation for matrices but that does not make them vectors. On the other hand, we may have tensors without using tensor notation as is evidenced by the fact that the German mathematician Voigt, who originated the idea of a tensor, never omitted the summation sign, as is now done, and did not use dummy indices. There seems to be nothing against the use of tensor notation, except perhaps that it is too condensed, but if it is used it seems reasonable to demand that tensors really be involved in the discussion.

V. Karapetoff (Cornell University, Ithaca, N. Y.): Tensor analysis has been proved to be a powerful tool in the solution of quite advanced electrical problems; it is of interest to note, however, that some simpler problems involving stationary networks require only matrix algebra. This means that students of the subject may be able to solve a certain class of problems without going into the general theory of invariants. In particular, it has been felt that some of the earlier treatment in Kron's epoch-making articles in the *General Electric Review* (volume 38, page 231) could be developed in greater detail and shown to agree with Kirchhoff's law, without explicitly using power as an invariant.

Let figure 1 represent a stationary network with impedances and sources of voltage (indicated by small circles) in each branch. Only instantaneous values of the currents and the voltages will be considered, so that it is immaterial whether the inserted voltages are direct or alternating, and whether the régime is steady or transient. The individual conductors (or branches) are denoted by the letters $a, b, \ldots. n, p$. The positive directions of the currents in the individual branches are arbitrary and are indicated by arrowheads. An applied voltage in a branch is to be considered positive if it tends to produce a current in the positive direction in that particular branch.

Following Maxwell (*Electricity and Magnetism*, volume 1, page 406), fictitious mesh currents, x, y, z, t, u, v, are introduced, with the positive directions arbitrarily taken clockwise. These currents are supposed

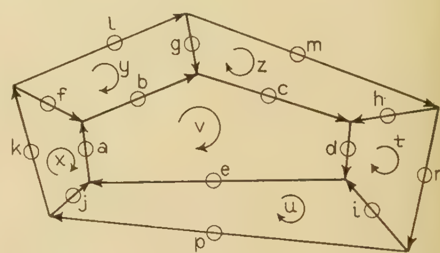


Fig. 1

to circulate in the individual loops of the network; an actual branch current is an algebraic sum of the corresponding mesh currents. For example, the current in a is equal to $v - x$. It is well known that in this manner Kirchhoff's first law is satisfied automatically and need not be expressed by separate equations. We shall use the following notation and terminology:

The individual conductors (or branches), the currents flowing through the same, and the inserted (or applied) voltages will all be denoted by the same symbols, $a, b, c, \ldots n, p$. No confusion need arise as to whether a current or a voltage is meant, or the conductor itself. The potential differences between the terminals of the respective conductors will be denoted by the corresponding capital letters, $A, B, C, \ldots N, P$. The letters x, y, z, t, u, v, will mean interchangeably the respective loops or meshes, the fictitious currents circulating around these meshes, and the sums of the applied voltages in the same meshes. Those sources of voltage which give a positive energy output with the corresponding mesh currents are to be considered positive, when summing up around that particular loop. As a test, a source may be replaced by a storage battery; if the positive mesh current discharges that battery, the voltage of the source is positive; if the battery is charged, the source is negative.

Consider now the matrix shown in figure 2, with the "branch" letters written to the left, and the "mesh" letters on top. The first row is to be interpreted as $a = -x + v$, that is, the current in conductor a is equal to that in mesh v less the current in mesh x; this agrees with the sketch of the network.

The other horizontal rows have a similar meaning for the other branches of the network, as may be readily verified. The matrix thus represents the relationship between the branch currents and the mesh currents. The number of rows is equal to that of the branches, and the number of columns to that of independent loops or meshes. The idea behind this representation is to refer Kirchhoff's first law to the same meshes for which the second law is written, and thus to have all the relations among the currents and among the voltages represented by the same matrix.

Now read the last column of the dyadic from the top down, assuming the letters to

$$C = \begin{array}{c|cccccc} & x & y & z & t & u & v \\ \hline a & -1 & & & & & 1 \\ b & & -1 & & & & 1 \\ c & & & -1 & & & 1 \\ d & & & & -1 & & 1 \\ e & & & & & -1 & 1 \\ f & 1 & -1 & & & & \\ g & & 1 & -1 & & & \\ h & & & 1 & -1 & & \\ i & & & & 1 & -1 & \\ j & -1 & & & & 1 & \\ k & 1 & & & & & \\ l & & 1 & & & & \\ m & & & 1 & & & \\ n & & & & 1 & & \\ p & & & & & 1 & \end{array}$$

Fig. 2.

refer to the voltages, and not to the currents. This column reads $v = a + b + c + d + e$, in other words, it states that the total applied voltage around the mesh v is equal to the sum of the applied voltages in the branches a, b, c, d, e. The other columns contain the corresponding relationships for the other meshes; a comparison with the network itself will show the signs of the voltages to be also correct. Thus, for the total current the dyadic is written using the current vector combinations $\boldsymbol{ax}$, $\boldsymbol{ay}$, etc., whereas for the voltage it is written with $\boldsymbol{xa}$, $\boldsymbol{xb}$, etc. The second dyadic is called transpose or conjugate with respect to the first. The underlying reason for which the same dyadic is correct for both the currents and the voltages is now seen to be that currents are added in parallel, whereas voltages are added in series. Consequently, following the mesh letters (x, y, z, etc.) horizontally by rows, one encounters the meshes between which a given conductor is situated. Following the branch letters vertically by columns (a, b, c, etc.) one follows the branches which combined form a given loop. In this manner, the representation by dyadics becomes firmly established on the basis of the fundamental electrical principles.

Let the impedance of the individual branches of the network be denoted by Z's with the corresponding double subscripts, the subscript nn meaning that the resistance, the self-inductance, and the capacitance of the n-th conductor or branch are meant. In a steady state, Z is a function of the frequency. In a transient state, the operator $p = d/dt$ is included in it. The mutual magnetic inductance between the n-th and the m-th branch is denoted by X_{mn}. It is identically equal to X_{nm}, and for this reason the impedance matrix of a stationary passive network is always symmetrical. In the dyadic notation Z stands for both Z_{nn} and X_{nm}, so that the general expression for the voltage drop in the individual branches is

$$\boldsymbol{E} + \boldsymbol{e} = \boldsymbol{Z} \cdot \boldsymbol{i} \qquad (1)$$

where $\boldsymbol{E}$ is the voltage between the terminals of the conductor and $\boldsymbol{e}$ is the sum of the external voltages inserted in the branch. The term $\boldsymbol{Z} \cdot \boldsymbol{i}$ includes a summation over all the branches which posses a mutual inductance with the branch under consideration. When summing up equation 1 over a closed mesh, the sum of the $\boldsymbol{E}$'s becomes zero, and we have the usual expression for Kirchhoff's second law.

In accordance with Kron's notation, let the vector of the fictitious currents circulating over the meshes be denoted by $\boldsymbol{i}'$, and the vector of the sums of the external applied voltages over the meshes by $\boldsymbol{e}'$. In other words, let $\boldsymbol{i}' = i_x\boldsymbol{x} + i_y\boldsymbol{y} +$ etc. Then, since all the relations are linear, we may write the dyadic expression in the form

$$\boldsymbol{e}' = \boldsymbol{Z}' \cdot \boldsymbol{i}' \qquad (2)$$

where $\boldsymbol{Z}'$ for the present simply stands for a dyadic of coefficients of proportionality between the new currents and the voltages. The relationship between $\boldsymbol{e}$ and $\boldsymbol{e}'$ on the one hand and between $\boldsymbol{i}$ and $\boldsymbol{i}'$ on the other hand is determined by the matrix in figure 2; consequently, there must be a definite dyadic relationship between the actual branch impedance $\boldsymbol{Z}$ and the new impedance $\boldsymbol{Z}'$. The components of the latter may be called mesh impedances or equivalent impedances, since they do not refer to the real branch currents, but to the fictitious mesh currents. Knowing $\boldsymbol{Z}'$ and $\boldsymbol{e}'$, these latter currents may be computed, and then the real branch currents calculated from the rows of the matrix in figure 2. Thus, our next problem is to find the relationship between $\boldsymbol{Z}$ and $\boldsymbol{Z}'$.

Let the matrix in figure 2 be denoted by $\boldsymbol{C}$. It is called a transformation matrix, because by means of it the variables are changed from the branch currents to the mesh currents. The physical circuit itself is not modified. Thus

$$\boldsymbol{i} = \boldsymbol{C} \cdot \boldsymbol{i}' \qquad (3)$$

For the voltages, the transpose matrix, $\boldsymbol{C}_t$, must be used, as is explained above, and we have

$$\boldsymbol{e}' = \boldsymbol{C}_t \cdot \boldsymbol{e} \qquad (4)$$

This equation may also be written as

$$\boldsymbol{e}' = \boldsymbol{C}_t \cdot (\boldsymbol{E} + \boldsymbol{e}) \qquad (5)$$

because a summation of the E's over a mesh gives zero. From equations 1, 2, 3, and 5, the relationship between $\boldsymbol{Z}$ and $\boldsymbol{Z}'$ may be determined as follows: Multiplying both sides of equation 1 by $\boldsymbol{C}_t$ and substituting for the left-hand side its value from equation 2 we get:

$$\boldsymbol{Z}' \cdot \boldsymbol{i}' = \boldsymbol{C}_t \cdot \boldsymbol{Z} \cdot \boldsymbol{i}$$

Using the value of $\boldsymbol{i}$ from equation 3 and cancelling $\boldsymbol{i}'$, we finally obtain

$$\boldsymbol{Z}' = \boldsymbol{C}_t \cdot \boldsymbol{Z} \cdot \boldsymbol{C} \qquad (6)$$

This is Kron's equation 19, and from here on the procedure is the same as in his articles, namely: First find $\boldsymbol{Z}'$ as on page 232, and then compute $\boldsymbol{Y}' = 1/\boldsymbol{Z}'$. Multiply vector $\boldsymbol{e}'$ by $\boldsymbol{Y}'$. This will give the mesh currents $\boldsymbol{i}' = \boldsymbol{Y}' \cdot \boldsymbol{e}'$. Finally determine $\boldsymbol{i}$ from $\boldsymbol{i}'$ by using the transformation matrix C.

In the foregoing deduction of equation 6, it has not been necessary to introduce the power output, $\boldsymbol{P} = \boldsymbol{i} \cdot \boldsymbol{e} = \boldsymbol{i}' \cdot \boldsymbol{e}'$, as an invariant. In fact, this mode of approach permits to deduce that the power is an invariant. Branch currents are changed to the mesh currents, but physically everything remains the same. Another advantage is that the inverse of the dyadic $\boldsymbol{C}_t$ is not used in the deduction of equation 6. The dyadic being singular in its very nature, its determinant is equal to zero; therefore, it is preferable not to use $\boldsymbol{C}_t^{-1}$ at all.

Because the transformation formulas are not derived from an invariant form, the foregoing deduction is not an example of tensor analysis; one is not permitted to use lower and upper indices in that sense. It is of interest to investigate the possibilities of generalizing this method, for example, by opening the network at a few points and connecting another circuit to it.

Joseph Slepian (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The first basis of good mathematics is probably the careful definition of terms. We have learned to follow and even improve upon the model set by Euclid, and to desire that each new term introduced into a mathematical work will be given a careful, and precise definition. We hope that the definition will have content. That is, that it should be free from self contradiction, and actually apply to some object. We hope that the definition will be sufficient. That is, that it will state all the qualities or properties necessary to distinguish the defined object from other objects. We hope the definition will be permanent. That is, that the meaning of the newly defined term will stay the same throughout the mathematical work. Lastly, we hope that so far as possible, the definition will conform to previous usage. The more widespread that previous usage, the less will we approve of any radical departure from previously used meanings.

The papers of Kron and Boyajian, appear to me to err in all these respects. Their definitions of the new terms or concepts which they introduce, seem mutually contradictory, insufficient, impermanent, and differ from previous and generally accepted usage.

From the titles of the papers, we would expect at least that adequate definitions of the "tensor" would be given. Also since the tensor is generally believed to be a generalization of the "vector," and opinion

apparently concurred with by Boyajian, but dissented from by Kron, we would expect an adequate definition of the "vector."

Kron, in his paper, page 1221, 1st column, refers to *General Electric Review*, volume 38 April 1935, page 181–91, and May 1935, page 230–43, "in which all the necessary definitions are stated." Turning to these references, we find in the first, page 181, first column, "the theory of tensors (known also under the name of hypercomplex numbers, polyadics, matrices, etc.)." Apparently then, the as yet undefined terms "tensors," "hypercomplex numbers," polyadics," "matrices," "etc., "all stand for the same thing. Perhaps a little dismayed by the plethora of names, including the "etc." for the same thing, we nevertheless proceed on in the reference.

The next suggestion of a definition we find on page 182, second column, "...replaced by hypercomplex numbers, that is, by sets of numbers arranged in a row (vector) or a square (matrix), etc." Here the terms "vector" and "matrix" seem to be no longer equivalent to the term "hypercomplex numbers," as before, but now the "vector" and "matrix" seem to be special cases of "hypercomplex numbers." "Vector" seems to refer to the capability of a set of numbers of being arranged in a row. Since, however, any set of numbers can obviously be arranged in a row, at least if it is a finite set, we seem to be told that any finite set of numbers is a "vector." Likewise "matrix" seems to refer to the capability of a set of numbers of being arranged in a square. But since any n^2 numbers, where n is an integer, can be arranged in a square, we seem to be told that any set of n^2 numbers is a "matrix." These n^2 numbers, if we like can also be arranged in a row, so apparently a "matrix" is also a "vector."

Proceeding further in the reference, we find after $3^1/_2$ full pages of text, the first explicit definition, page 184, column 2, "An expression such as $(e_a a + e_b b + e_c c)$ ...is called a vector." Apparently, now, to be a "vector," the set of numbers must not only be placed in a row, but must be written with symbols, a, b, c, following each number, and with plus signs between successive numbers. But since obviously, any finite set of numbers can be set down in this way, if the writer chooses, again we seem to be told that any finite set of numbers is a "vector."

Boyajian is even more outspoken in enunciating this view, although there is some suggestion of uneasiness about a necessary relationship of the set of numbers to reference axes. Thus (Electrical Engineering, August 1936, page 857, column 2), "Stated broadly, a vector is a quantity resolvable into a set of independent components." Again (Electrical Engineering, August 1936, page 858, columns 1 and 2), "to constitute a generalized vector, the set of quantities $e_1 e_2 \ldots e_n$ need not represent a physically directed quantity in space, nor a harmonic quantity in time; in fact, it is not necessary to know what physical quantity they represent, in order to decide whether or not they constitute a generalized vector. They may be considered, at least tentatively, as constituting a generalized vector...if they ...constitute one group of related but independent quantities."

Since the members of any set of numbers are related, by being parts of one set, and independent, by being distinct from one another, Boyajian apparently also believes that any finite set of numbers is, "at least tentatively," a vector.

Thus according to these views, we have so bizarre a "vector" as today's closing quotations of the New York Stock Exchange. These are certainly a group of related quantities; in fact they are printed on the same newspaper page because of their common quality. That they vary independently, any speculator can testify. Although in the newspaper, they are usually arranged in columns, they could be arranged in a row. Actually on the ticker tape they are so arranged, and each number has set beside it a symbol, as *GM* $68^1/_2$... *GE* $59^1/_8$ ... *UP* 128, which, except for the absence of plus signs, is very reminiscent of Kron's $e_a a + e_b b + e_c c$. Apparently according to the definitions of Kron and Boyajian, the stock market quotations are "at least tentatively" a vector.

But these definitions are entirely different from the generally accepted meanings given to vectors. Let us limit outselves to vectors in ordinary Euclidean space. All the usual treatments of vectors in Euclidean space begin by assigning to vectors the notions of length or magnitude, and direction. These seem to be the primary defining properties of vectors which practically all text books agree upon. "Components" then come in only as the appropriate mathematical means for describing magnitude and direction.

In these days of relativity, we are all aware that length and direction have no absolute significance. We cannot describe the direction of a vector except with reference to other objects having direction, nor can we specify its length except with reference to some other object having length. Thus the "components" of a vector which mathematicians introduce to properly describe its length and direction are not absolute, but are relative to some system of reference object which themselves have length and direction. The "components" of a vector are relative to a reference system of vectors.

A vector, then, has not one set of components, but infinitely many sets, one for every vector reference system that may be chosen. Furthermore, all these various sets of components must be mutually related so that each in its own reference system indicates the same "directed magnitude." The so-called transformation equations which the sets of components must satisfy are merely the expression of the property of the vector of having length and direction.

A displacement in space which is the typical vector, has length and direction, and therefore has infinitely many mutually related sets of components referred to the various possible reference displacement systems, but the report of stock market quotations, which has only one set of components, has neither length nor direction and is not a vector according to usual notions.

Evidently the definitions of Kron and Boyajian which make an arbitrary set of numbers, such as a stock market report, a vector, "at least tentatively," must differ very radically from the generally accepted meaning given to "vector."

If we pursue further the reference given by Kron, we go through over 15 pages of text with the word tensor used scores of times. Although they are as yet undefined, "tensors," "dyadics," "polyadics," "matrices," "hypercomplex numbers," and "etc.," seem to be used indiscriminately synonomously. But, at last, page 234, we come to section VII, "Definition of a Tensor." We learn, "those polyadics whose formulas of transformation are the simple ones given in equations 37 are called 'tensors,'...the word tensor is limited to a definite class of polyadics..." Apparently the preceding use of the words "tensor" and "polyadic" as synonymous in Kron's work was a mistake.

Boyajian seems to be able to use the word "tensor" without requiring "polyadics." But his test for the tensor quality of his "transformation tensor" on page 862, seems to involve only such manipulation of indices as Kron performs upon all his "polyadics," which Kron states are not always "tensors." May I ask Boyajian whether his test may not merely demonstrate the "Kronian polyadic?" quality of his "transformation tensor" and perhaps not its tensor quality.

Going a little further in Kron's reference, page 234, column 2, "Whether a vector or a dyadic, etc., is a tensor or not, does not depend...." Apparently according to Kron a vector need not always be a tensor. However, every book, which I have consulted makes the vector a special case of a tensor, that is, a tensor of rank one. Boyajian also in his paper, says, page 857, column 2, "vectors come in as a special class of tensors" and page 860, column 1, "the common vector is merely a special case as a one-dimensional tensor, or a tensor of rank one." Can Kron justify his usage of the word vector which seems to differ from that of all others?

On page 235, column 2, of his reference, Kron becomes even more specific. He now says that a vector has "length," or magnitude, and "If the magnitude of a vector is the same irrespective of the co-ordinate system...it is called a tensor."

But Kron gives no definition of the "length" or "magnitude" of a vector. Would he find the "length" of the vector current such as he uses in his present paper by taking the scalar product of it with itself, meaning thereby the sum of the squares of its components? If so, then he would violate his rules for manipulating indices. But how otherwise? A similar question might be addressed to Boyajian who, on page 858, column 2, gives examples of a purportedly purely contravariant vector, and a purportedly purely covariant vector, each having length or magnitude. However, whatever the resolution of this dilemma may be, Boyajian, contrary to Kron, seems willing to let the lengths or magnitudes of his vectors vary with transformation of co-ordinates, without their losing their tensor character.

We might also ask Kron whether his criterion for the tensor character of a vector last quoted is consistent with the previously quoted "Definition of a Tensor" as those "polyadics" which satisfy the "equations" 37. If the components of a vector satisfy the "equations" 37 will its

"length" necessarily be unchanged by the transformation and vice versa?

One more question of definition. On page 239, column 1, of Kron's reference, we find "A tensor whose elements are complex numbers is called a spinor." Since "spinors" are used now quite widely in the literature of quantum-mechanics, and not at all in the sense of the quoted definition, will Kron give one reference to justify his definition?

I have already intimated that I believe Boyajian's treatment of covariance and contravariance to be unsound. If the space under consideration is metrical, as seems to be the case since Boyajian refers to the "magnitude" of his vectors, then any vector has both covariant and contravariant components as Sah brings out in his second paper in the section "Covariant and Contravariant Measure Numbers."

Refer to the equation in Kron's paper, page 1231, bottom of second column. This gives a relation between the components of the variables ΔX in the "old reference system" ΔX^m and the "new," ΔX^α. Is it not then the "transformation equation" and therefore does it not define the "transformation tensor?" But on page 1224, second column, we find "In this presentation all transformation tensors have only constant components..." In other words, is there not a contradiction with equations 38?

In Kron's paper page 1233, first column, the complex number

$$\Delta \hat{e}_1 = \Delta e_1 + j\Delta e_1'$$

is set down equal to a real number. Is this not a contradiction? The title of this section is called complex Taylor's series. But "Taylor's series" usually means the expansion of a function of a variable into a power series, such as equation 61 where the coefficient in each term is $1/n!$ times the value of the nth derivative of the function taken at some definite point. I fail to find any such expanison in this section. How does Kron justify the title, "Taylor's Series?"

In this section, where the applied voltage Δe is supposed to be resolvable into n components with different frequencies, it is said that there will in general be $n+2n^2$ components of current, (if, as I presume, higher powers than the second of the component Δe's are neglected). Apparently the only distinguishing or defining feature of these components is their frequency. But, even in the most general case there will not by as many as $n+2n^2$ different frequencies. For obviously in the square array of component currents shown in the second column of page 1233, the frequency $w_1 + w_2$ is equal to the frequency $w_2 + w_1$, etc. Hence in this square array there will in general be only $^1/_2 n(n+1)$ distinct frequencies. Does Kron intend the component $\Delta i^{w_2+w_1}$ to be different from $\Delta i^{w_1+w_2}$? If so, will he not need a different notation? Or is $w_1 + w_2$ not equal to $w_2 + w_1$? Will the total current Δi always contain the two terms $\Delta i^{w_1+w_2} + \Delta i^{w_2+w_1}$ always summed together? If so, why not use only a single letter for this sum, since the component terms can never be determined by any test, and may therefore perhaps be said not to exist individually.

Similar remarks may be applied to the matrix for $\Delta i^{(\alpha)(-\beta)}$. The frequency $w_1 - w_2$ is the negative of the frequency $w_2 - w_1$. Does Kron permit the frequency to be negative? If so, how do these negative frequencies make their presence apparent? If not, then $^1/_2 n(n-1)$ of the n^2 frequencies referred to in $\Delta i^{(\alpha)(-\beta)}$ disappear. Also in the matrix for $\Delta i^{(\alpha)(-\beta)}$ the frequencies for the diagonal terms are all alike and zero. Apparently even in the most general case there are for these $n+2n^2$ components of current only n^2+n+1 distinct frequencies But if the $n+2n^2$ components of current dealt with in this section are not defined by their individual frequencies, how are they defined?

In the next section, page 1234, entitled "Compound Series," Kron assumes that for any given total impressed voltage it is somehow possible to separate and distinguish components of "fundamental frequency" from components of "product frequency." But such a resolution is not at all unique. For example, suppose we have actually impressed upon a system a voltage having components of 10, 15, 25, and 35 cycles, and let us say each of these components has the value one. Then if we like, we may regard these all as "fundamental frequencies," and in Kron's equation 85 set $\Delta e_{(\sigma)}$, and $\Delta e_{(\gamma)}\ \Delta e_{(\delta)}$, each as unity, and the $\Delta e_{(\gamma)\ (\pm\delta)}$ each as zero. But we may, if we like, take only the 10 and 25 cycles as fundamental, and regard the 15 and 35 cycles as product frequencies. Then in Kron's equation 55, $\Delta e_{(\sigma)}$ stands for Δe_{10} and Δe_{25}, each to be taken as one; $\Delta e_{(\gamma)}$, $\Delta e_{(\delta)}$ also stand for Δe_{10} and Δe_{25} and each to be taken as one. But $\Delta e_{(\gamma)\ (\pm\delta)}$ now stand for $\Delta e_{25\ \pm\ 10}$, that is for Δe_{15} and Δe_{35} and are now to be taken as unity. Similarly we may take 10, 15, and 25 cycles as fundamental and regard only the 35 cycles as product frequency. Since each of these equally plausible ways of regarding the applied voltage, when applied to the equation 85 would seem to give different results, some doubt may be cast upon the correctness of the treatment.

At the end of this section, page 1234, column 1, it states that "all symbols,—such as $Z_{(\epsilon)(\sigma)}$are not "polyadics" (as defined in reference $1Da$)...." This contradicts the statement quoted earlier that "all the necessary definitions are stated" in reference $1A$. It is most disconcerting, after receiving the impression in Kron's reference, from April 1935 to Jan. 1936, that "polyadics" and "hypercomplex numbers" are synonymous, to at last receive a definition in February 1936, which makes them different.

The section called "Inverse of the Complex Series," on page 1236, seems to deal with what were called "Compound Series" on page 1234.

Here, again, the lack of definition enabling one to distinguish between $\Delta i^{w_1+w_2}$ and $\Delta i^{w_2+w_1}$, and the ambiguity as to what are to be called "fundamental frequency" and what "product frequency" make the value of the work seem quite doubtful.

A. P. T. Sah (National Tsing Hua University, Peiping, China): The gateway to Kron's work hinges on his "connection tensor" C. It is unfortunate that Kron has not explained this fundamental quantity clearly in his writings, since 2 easily recognized inconsistencies in the exposition of the "connection tensor" C have appeared in his papers. In the first place the "connection tensor," by its very nature, is necessarily singular and cannot have a reciprocal. And yet the reciprocal of C or of its transpose has been not only written down in explicit equations (See equation 37, *General Electric Review*, volume 38, page 234, May 1935 and equation 38, Electrical Engineering, page 1226, November 1936) but also used in making demonstrations. The second inconsistency has to do with Kron's "generalized network" (See figure 4, Electrical Engineering, page 1228, November 1936). In figure 4*a*, the so-called "generalized network" is shown with all coils short-circuited through applied electromotive forces. From such a diagram one would necessarily conclude that the currents in the coils are uniquely determined when all the electromotive forces and the impedances are known. But these current values cannot satisfy the constraining conditions as shown in figure 4*b* for the same applied electromotive forces and the impedances of figure 4*a*. It is believed that Kron's generalized network is entirely uncalled for since it represents neither a mathematical fiction nor a physical reality. In fact, it is in plain contradiction with the physics of the problem

Leaving aside the question of the *engineering* utility of the "connection tensor" in setting up circuit equations in any case, which, as correctly pointed out by Bewley (Electrical Engineering, page 1215 November 1936), is neither simpler nor shorter than the old-fashioned Kirchoff's laws, it is hoped that Kron will revise his statements and demonstrations so as to make his "connection tensor" a flawless tool.

A. W. Tucker (nonmember; Princeton University, Princeton, N. J.): Professor Struik has pointed out that my recent work on tensor algebra in topology has a bearing on the applications of tensors to electrical engineering. To illustrate let us consider a network consisting of (directed) lines numbered 1, 2, 3, etc. and terminals I, II, III, etc.; an example, with figure, is given below. The combinatorial structure of such a network is exhibited by the array of *incidence numbers*.

$$N_a{}^\alpha = \begin{cases} 1 & \text{if the line } a \text{ ends at the terminal } \alpha \\ -1 & \text{if the line } a \text{ begins at the terminal } \alpha \\ 0 & \text{otherwise.} \end{cases}$$

In each line a let there be a current component e^a and at each terminal α a component h_α of potential. Then, using the summation convention,

$$f^\alpha = N_a{}^\alpha e^a \qquad (1)$$

$$i_a = h_\alpha N_a{}^\alpha \qquad (2)$$

$$p = i_a e^a = h_\alpha N_a{}^\alpha e^a = h_\alpha f^\alpha \qquad (3)$$

measure (1) the current flowing out of the network at the terminal α (say, into an external lead), (2) the voltage in the line a, and (3) the power in the network. If we now consider the same network in terms of

new elements 1′, 2′, 3′, etc. and I′, II′, III′, etc. formed from the old by a reversible process, we get new incidence numbers

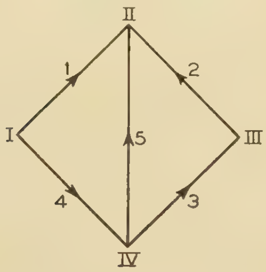
$$N_{a'}^{\alpha'} = C_{\alpha}^{\alpha'} N_a^{\alpha} C_{a'}^{a}$$

and new components of current, potential, voltage, etc.,

$$e^{a'} = C_a^{a'} e^a,\ h_{\alpha'} = h_{\alpha} C_{\alpha'}^{\alpha},\ i_{a'} = h_{\alpha'} N_{a'}^{\alpha'} = h_{\alpha} N_a^{\alpha} C_{a'}^{a}, \text{ etc.},$$

where $C_{a'}^{a}$, $C_a^{a'}$ are inverse transformations (i.e. $C_{a'}^{a}\, C_b^{a'} = 1$ if $a = b$ and 0 otherwise) as are $C_{\alpha'}^{\alpha}$, $C_{\alpha}^{\alpha'}$.

Example



incidence table

	1	2	3	4	5
I	−1	0	0	−1	0
II	1	1	0	0	1
III	0	−1	1	0	0
IV	0	0	−1	1	−1

$= N_a^{\alpha}$

change of line-basis:

$$1' = 1,\ 2' = 2,\ 3' = 3,\ 4' = 4 + 5 - 1,\ 5' = 5 - 2 - 3$$

	1′	2′	3′	4′	5′
1	1	0	0	−1	0
2	0	1	0	0	−1
3	0	0	1	0	−1
4	0	0	0	1	0
5	0	0	0	1	1

$= C_{a'}^{a}$

	1	2	3	4	5
1′	1	0	0	1	0
2′	0	1	0	−1	1
3′	0	0	1	−1	1
4′	0	0	0	1	0
5′	0	0	0	−1	1

$= C_a^{a'}$

change of terminal-basis:

I′ = II − I II′ = II − III
III′ = II − IV IV′ = IV

	I′	II′	III′	IV′
I	−1	0	0	0
II	1	1	0	0
III	0	−1	1	0
IV	0	0	−1	1

$= C_{\alpha'}^{\alpha}$

	I	II	III	IV
I′	−1	0	0	0
II′	1	1	0	0
III′	1	1	1	0
IV′	1	1	1	1

$= C_{\alpha}^{\alpha'}$

incidence table with respect to new bases

	1′	2′	3′	4′	5′
I′	1	0	0	0	0
II′	0	1	0	0	0
III′	0	0	1	0	0
IV′	0	0	0	0	0

$= N_{a'}^{\alpha'}$

In topological parlance a network of lines and terminals is a *graph* of *edges* and *vertices* or a *1-complex* (i.e. one-dimensional complex) of 1-cells and 0-cells. Numbers e^a attached to the 1-cells give a *1-chain.* The numbers $f^{\alpha} = N_a^{\alpha} e^a$ attached to the 0-cells give a special 0-chain called the *boundary* of the preceding 1-chain. Notice that Kirchhoff's law asserts that the boundary of a current vanishes—except at terminals with external connections. Numbers h_{α} attached to the 0-cells give a "dual" 0-chain—here the terminology is not well established for the notion is new. The "dual" boundary of this is the dual 1-chain given by the numbers $i_a = h_{\alpha} N_a^{\alpha}$ attached to the 1-cells. Instead of basing our chains on cells we may base them on suitable combinations of cells (i.e. chains). Thus we are led to consider *changes of basis.* The particular changes chosen in the above example serve to reduce the table of incidence to an especially simple form. The components of a chain such as current change contravariantly and those of a dual chain such as voltage change covariantly; hence their scalar product, or *intersection index*, is invariant under change of basis.

I hope these remarks indicate how topology enters as an intermediary in the application of tensors to electrical engineering. There is nothing new in the separate items of the above discussion; the only novelty lies in putting them together. The topology involved seems quite essential although being one-dimensional it is rather trivial from the geometrical point of view. However it is far from ruled out that higher dimensions may not come into the development as it unfolds.

C. E. Rose (Federal Emergency Administration, Washington, D. C.): Vector and tensor symbols will be written in capital type and since a vector is in reality a tensor of rank zero no ambiguity will result, because in this convention a vector will be defined as such by being without a sub- or superscript, whereas a tensor will always be written with its definitive subscripts and / or superscripts. Given any 2 arbitrary vectors A and B, existing within orthogonal or affine space, we write their product as AB. This is neither their scalar product $A{\cdot}B$, not their vector product $A \times B$, and it is therefore at this point undetermined.

Write:

$$A = a_1 i + a_2 j + a_3 k, \tag{1}$$

$$B = b_1 i + b_2 j + b_3 k \tag{2}$$

in which i, j, and k are the unit vectors and a_1, a_2, a_3 and b_1, b_2, b_3 are the respective projections of A and B upon the axes measured by these respective unit vectors.

We know from elementary vector analysis that:

$$i \cdot i = j \cdot j = k \cdot k = 1 \tag{3}$$

$$i \cdot j = j \cdot k = k \cdot i = 0 \tag{4}$$

as the scalar products of these unit vectors.

We also know that:

$$i \times i = j \times j = k \times k = 0 \tag{5}$$

$$i \times j = -j \times i = k \tag{6}$$

$$j \times k = -k \times j = i \tag{7}$$

$$k \times i = -i \times k = j \tag{8}$$

as the vector products of these unit vectors.

We, therefore, now write the product of equations 1 and 2 as:

$$AB = a_1b_1ii + a_1b_2ij + a_1b_3ik + a_2b_1ji + a_2b_2jj + a_2b_3jk + a_3b_1ki + a_3b_2kj + a_3b_3ik \tag{9}$$

We may now, as usual, substitute a_{11}, a_{12} .....a_{33} for the coefficients of a_1b_1, a_1b_2... ....a_3b_3 above, and write the scalar product of AB as, the matrix:

$$A \cdot B = \begin{Vmatrix} a_{11}a_1b_1 & 0 & 0 \\ 0 & a_{22}a_2b_2 & 0 \\ 0 & 0 & a_{33}a_3b_3 \end{Vmatrix} \tag{10}$$

and the vector product of AB as, the matrix:

$$A \times B = \begin{Vmatrix} 0 & a_{12}a_1b_2 & -a_{13}a_1b_3 \\ -a_{21}a_2b_1 & 0 & a_{23}a_2b_3 \\ a_{31}a_3b_1 & -a_{32}a_3b_2 & 0 \end{Vmatrix} \tag{11}$$

add equations 10 and 11, yields:

$$AB = (A \cdot B) + (A \times B) = \begin{Vmatrix} a_{11}a_1b_1 & a_{12}a_1b_2 & a_{13}a_1b_3 \\ a_{21}a_2b_1 & a_{22}a_2b_2 & a_{23}a_2b_3 \\ a_{31}a_3b_1 & a_{32}a_3b_2 & a_{33}a_3b_3 \end{Vmatrix} \tag{12}$$

We may further condense equation 12 and write:

$$AB = \sum_{ik} a_{ik}a_ibk = \begin{Vmatrix} a_{11}a_1b_1 + a_{12}a_1b_2 + a_{13}a_1b_3 + \\ a_{21}a_2b_1 + a_{22}a_2b_2 + a_{23}a_2b_3 + \\ a_{31}a_3b_1 + a_{32}a_3b_2 + a_{33}a_3b_3 \end{Vmatrix} \tag{13}$$

If the right hand member of equation 13 remains invariant in form when subjected to any rotation about its co-ordinates, then we may write in tensor notation:

$$T_{ik} = \sum_{ik} a_{ik}a_ib_k \tag{14}$$

and equation 14 defines a covariant tensor of rank 2.

To test whether equation 14 is invariant let us rewrite equation 9 as before and rotate it 90 degrees around the i-axis. To do so write:

$$AB = \begin{Vmatrix} a_1b_1ii + a_1b_2ij + a_1b_3ik + \\ a_2b_1ji + a_2b_2jj + a_2b_3jk + \\ a_3b_1ki + a_3b_2kj + a_3b_3kk \end{Vmatrix} \tag{9}$$

and to apply to it the versor:

$$\phi = ii \cos e(jj + kk) + \sin e\,(kj - jk) \tag{15}$$

Since the original unit vectors in equation 9 are i, j and k, then by multiplication of equation 9 by equation 15 we have rotated equation 9 90 degrees around the i-axis and

$$\begin{aligned} i' &= i \\ j' &= j \cos e + k \sin e, \\ k' &= -j \sin e + k \cos e \end{aligned} \tag{16}$$

e, the angular rotation in this cases being 90 degrees, equation 16 reduces to

$$\begin{aligned} i' &= i \\ j' &= k \\ k' &= -j \end{aligned} \quad \text{or} \quad \begin{aligned} i &= i' \\ j &= -k' \\ k &= j' \end{aligned} \tag{17}$$

Substitution of the values of i, j and k, in terms of i', j', and k' from equation 17 into equation 9 yields:

$$AB = \left\|\begin{matrix} a_1b_1i'i' - a_1b_2i'k' + a_1b_3i'j' - \\ a_2b_1k'i' + a_2b_2k'k' - a_2b_3k_1j' + \\ a_3b_1j'i' - a_3b_2j'k' + a_3b_3j'j' \end{matrix}\right\| \quad (18)$$

which is identical in form to equation 9. We may designate the coefficients as usual of the components $a_1b_1 \ldots a_3$, by $a_{11} \ldots a_{33}$ without losing any generality and the result is again equation 13, which proves that equation 9 and its developments, equations 12, 13, and 14, define a tensor, because its form is identical after this rotation of 90 degrees.

A contravariant tensor represents the "Path"; a covariant tensor represents the force along the "Path"; the first is defined by superscripts, the second by subscripts and the mixed tensor by both, as A^{ik}, A_{ik}, and A_i^k respectively.

Induction Motors on Unbalanced Voltages

Discussion and authors' closure of a paper by H. R. Reed and R. J. W. Koopman published in the November 1936 issue, pages 1206–13, and presented for oral discussion at the induction machinery session of the winter convention, New York, N. Y., January 27, 1937.

H. J. Reeves (Paul and Reeves, Spokane, Wash.): The authors treatment of the 3-phase motor on single-phase voltage might be presented in a slightly different manner. Sketch B of their paper could be

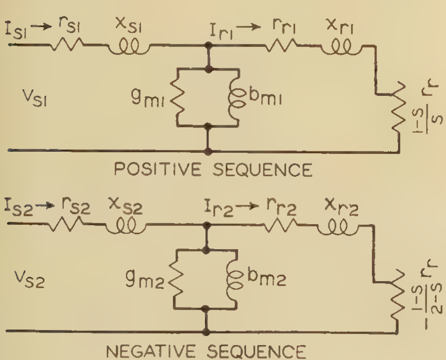


Fig. 1

changed to show the separate sequence circuits as in figure 1 of this discussion.

For the negative sequence circuit, the slip, S_2, is equal to 2 minus the positive sequence slip S_1. Thus,

$$\frac{1 - S_2}{S_2} = \frac{1 - 2 + S_1}{2 - S_1}$$

$$= -\frac{1 - S}{2 - S}$$

where S_1 is made equal to S for the sake of brevity.

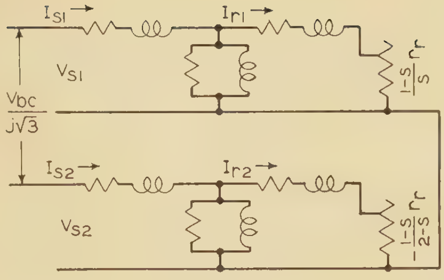


Fig. 2

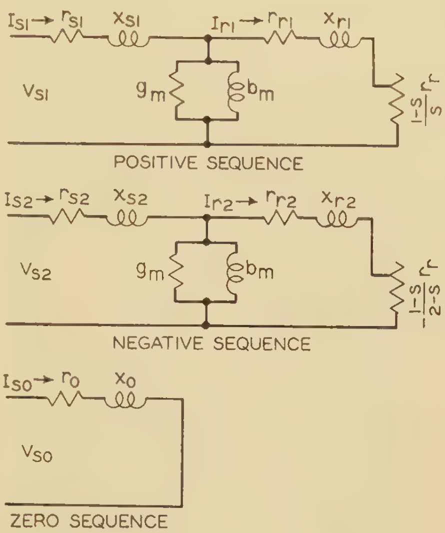


Fig. 3

For the 3-phase motor operating single phase we may assume a phase open. The following relations will hold:

$$I_a = 0$$
$$I_b = I$$
$$I_c = I$$
$$I_{s1} = {}^1/_3\,(0 + \alpha I - \alpha^2 I) = \frac{\alpha - \alpha^2}{3} I = \frac{j}{\sqrt{3}} I$$
$$I_{s2} = {}^1/_3\,(0 + \alpha^2 I - \alpha I) = \frac{\alpha^2 - \alpha}{3} I = -I_{s1}$$

$$V_b = \alpha^2 V_{s1} + \alpha V_{s2}$$
$$V_c = \alpha V_{s1} + \alpha^2 V_{s2}$$
$$V_{bc} = V_c - V_b = (\alpha - \alpha^2) V_{s1} + (\alpha^2 - \alpha) V_{s2} = (\alpha - \alpha^2)(V_{s1} - V_{s2}) = j(\sqrt{3} V_{s1} - V_{s2})$$

$$I_{s1} = I_{s2} \quad (1)$$

$$\frac{V_{bc}}{j\sqrt{3}} = V_{s1} - V_{s2} \quad (2)$$

For analytical purposes, connect the sequence networks together as in figure 2 to satisfy the conditions of equations 1 and 2. This solution will permit the use of the familiar tabulation in columnar form for the calculation of motor performance curves. To the table for balanced 3-phase voltage operation will be added the negative-sequence calculations for the corresponding values of slip, and the changes in positive-sequence values resulting from the changes in positive-sequence voltage.

The practical limits of $\frac{1 - S}{S} r_r$ are zero and infinity, and of $-\frac{1 - S}{2 - S} r_r$ are zero and $-0.5r_r$. It will be noted that in the working range, $-\frac{1 - S}{2 - S}$ may be assumed to be -0.5 without appreciable error. Since the values of negative-sequence voltage near synchronous speed are low we may assume

$$I_{\gamma 2} = I_{s1}$$

and the negative sequence torque will then be

$$T_2 = -0.176 \frac{Pr_r}{f(2 - S)} I_{s1}^2$$

The loss in speed necessary for a balance between negative and positive sequence torques is slight and is usually less than one per cent.

Another interesting application can be made to the Y-connected motor operating on a 4-wire 3-phase circuit, with one of the phase wires open. A motor operating under this condition will have considerable starting torque, since a positive angular displacement between the 2-phase windings is maintained. The following solution for this condition might be used.

$$I_a = 0 = I_1 + I_2 + I_0 \quad (3)$$

$$I_b + I_c + I_N = 0$$

$$\begin{aligned} V_b &= \alpha^2 V_1 + \alpha V_2 + V_0 \quad (4) \\ &= \alpha^2 I_1Z_1 + \alpha I_2 V_2 - (I_1 + I_2) Z_0 \\ &= I_1 (\alpha^2 Z_1 - Z_0) + I_2 (\alpha Z_2 - Z_0) \end{aligned}$$

$$I_2 = \frac{V_b - I_1(\alpha^2 Z_1 - Z_0)}{\alpha Z_2 - Z_0} \quad (6)$$

$$\begin{aligned} V_c &= \alpha V_1 + \alpha^2 V_2 + V_0 \\ &= \alpha I_1Z_1 + \alpha^2 I_2Z_2 - (I_1 + I_2)Z_0 \\ &= I_1 (\alpha Z_1 - Z_0) + I_2 (\alpha^2 Z^2 - Z_0) \quad (5) \end{aligned}$$

$$= I_1 (\alpha Z_1 - Z_0) + \frac{V_b - I_1(\alpha^2 Z_1 - Z_0)}{\alpha Z_2 - Z_0} \times (\alpha^2 Z_2 - Z_0)$$

$$I_1 = \frac{V_c(\alpha Z_2 - Z_0) - V_b(\alpha^2 Z_2 - Z_0)}{(\alpha Z_1 - Z_0)(\alpha Z_2 - Z_0) - (\alpha^2 Z_1 - Z_0)} \times (\alpha^2 Z_2 - Z_0) \quad (7)$$

The sequence networks are shown in figure 3. These should be connected together to satisfy the conditions of equations 3, 4, and 5, but as this condition does not lend itself readily for simple solution, I_1 may be calculated from equation 7 and I_2 from 6.

For this solution the values for 3-phase balanced operation may be utilized and the values for the negative-sequence circuit may be taken from the additions which have been noted above.

The starting torque and current values of table I and the speed-torque characteristics of figure 4 have been calculated from the following constants of a 5-horsepower, 220-volt, 3-phase, 60-cycle, 6-pole motor, all being expressed in unit values.

$r_{s1} = r_{s2} = 0.044$	$X_{r1} = X_{r2} = 0.140$
$r_{r1} = r_{r2} = 0.067$	$X_0 = 0.140$
$r_0 = 0.044$	$g_m = 0.023$
$X_{s1} = X_{s2} = 0.140$	$b_m = 0.380$

Table I

	A	B	C
Starting current	3.42	3.42	3.74/3.93
Starting torque	0.98	0	0.51
Maximum power	1.67	0.76	1.23
Maximum torque	2.00	0.80	1.38
Unit current	1.00	1.00	1.00
Power	1.00	0.35	0.52
Speed	0.94	0.97	0.97
No load { Current	0.38	0.67	0.52
No load { Speed	1.00	1.00 −	1.00 −

A—Motor operating on balanced 3-phase voltage
B—Motor operating single-phase line-to-line voltage
C—Motor operating on 2 phases of the 3 line-to-neutral voltages

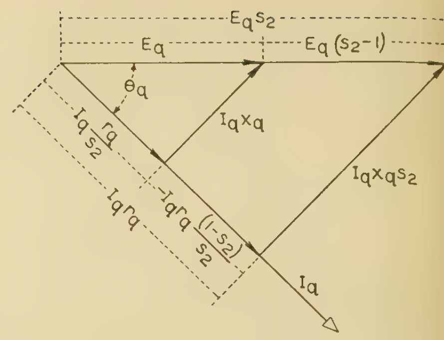


Fig. 4. Voltage and current relations in the rotor of the negative-sequence circuit

From a rotor point of view

$$I_q = \frac{E_q s_2}{r_q^2 - x_q^2 s_2^2}$$

From a stator point of view

$$I_q = \frac{E_q}{(r_q^2/s_2^2) - x_q^2}$$

Selby Haar (Board of Transportation, City of New York, N. Y.): Tests of a number of 3-phase squirrel cage rotor motors of 1 to $2^1/_2$ horsepower, presumably with balanced windings, on a circuit with approximately 1 per cent unbalance of voltages showed unbalanced currents as high as 20 per cent. If the motors are provided with controllers of standard type with overloads in 2 lines only, an overload setting sufficient to carry the larger current may be too high to protect the other phase windings of the motor. Hence unbalanced voltages in a polyphase supply system may be a serious matter.

G. F. Corcoran (The State University of Iowa, Iowa City.): The authors have combined symmetrical-component circuit theory with classical polyphase-induction-motor theory to advantage. By strict adherence to accepted principles in these 2 fields they have simplified the general problem of predetermination of induction-motor characteristics under unbalanced voltage conditions.

An important feature of the method presented in this paper is the absence of empirical constants and other data that can be obtained only by elaborate tests. No parameters other than those which can easily be calculated from ordinary test data or from ordinary design data have been employed in the calculations. It is obvious that g_e, b_e, and r_q are not exactly the same for the 2 equivalent circuits, namely, the positive-sequence circuit and the negative-sequence circuit. With the aid of empirical data and various assumptions several refinements in g_e, b_e, and r_q might be affected. However, the amount of additional labor involved and the inaccuracies encountered in obtaining actual magnetizing reactances discourage any general attempt in this connection.

For a particular operating condition, certain refinements are entirely feasible. For example, at low values of slip s_1 the negative-sequence voltage is low and g_e in the negative-sequence circuit could be adjusted accordingly with due regard for the saturation effects caused by the positive-sequence flux. It will be observed, however, that quite uniform results have been obtained neglecting "saturation effects" entirely. Also at low values of s_1 the approximate double-frequency rotor current in the negative-sequence circuit will make for higher rotor resistance and simultaneously there will be a high-frequency core loss. Both of these effects could, conceivably, be taken into account in the present method by increasing r_q in the negative-sequence circuit by the appropriate amount for each different value of slip. Refinements of this nature are, of course, incidental to the general theory involved because accurate results necessarily involve the use of accurate circuit parameters.

The remarkable feature of the present method is that the experimentally determined results agree as well as they do with those calculated on the basis of constant g_e, b_e, and r_q. As shown in the paper, the calculated values agree with the experimentally determined values better for low values of s_1 than for higher values of s_1. Certain irregularities due to inherent space harmonic effects are to be expected for particular low values of s_1.

The theory underlying the introduction of a negative resistance

$$r_q \frac{(1 - s_2)}{s_2}$$

where $s_2 > 1$

is of some importance because the electromagnetic power developed by the negative-sequence field is:

$$-\left[I_q^2 r_q \frac{(1 - s_2)}{s_2}\right] \tag{1}$$

In this connection it is interesting to note that power crossing the gap via the negative-sequence field is:

$$\left[I_q^2 \frac{r_q}{s_2}\right] \tag{2}$$

Physically, of course, there are $I_q^2 r_q$ watts dissipated in heat in the q branch of the negative-sequence circuit and this is supplied only partially by the power that crosses the gap via the negative-sequence field.

$$I_q^2 r_q = I_q^2 \frac{r_q}{s_2} - I_q^2 r_q \frac{(1 - s_2)}{s_2} \tag{3}$$

The voltage relations involved in the negative-sequence circuit when $s_2 > 1$ are shown in the accompanying sketch. A comparison of these relations with the well-known positive-sequence circuit relations when $s_1 < 1$ will further disclose the reason for the introduction of negative resistance into the negative-sequence equivalent circuit.

Although the present method as applied to the single-phase case possesses certain features which are contained in the common 2-network single-phase equivalent circuit, it is definitely superior in several respects. The voltage to employ in connection with each circuit can be calculated in a straightforward manner. This particular feature is distinctly advantageous in the single-phase case and it is thought that the present method of attack will find its greatest field of usefulness in single-phase motor analysis.

F. H. Pumphrey (Rutgers University, New Brunswick, N. J.): I have been interested in the presentation of this paper primarily as a teacher of the subject of electrical machinery. The schools have faced tremendous pressure to reduce the amount of time spent in the study of electrical machinery. One of the ways that this has been accomplished is by obtaining a closer coordination of the theory of machines. With this in view, several years ago, I discarded the cross-field theory of single-phase induction motor operation, and adopted the symmetrical-component analysis as presented in this paper. It has had several advantages. First, it has given an excellent illustration of the use of symmetrical components, second, it has permitted me to use all of the polyphase motor theory that had been built up and thus save time, and third, it has given, I believe, a better physical understanding of the phenomena. I should welcome comments from designing engineers as to the relative merits of the symmetrical-component attack versus the cross-field theory where time permits the presentation of but one.

P. H. Trickey (Diehl Manufacturing Company, Elizabethport, N. J.): Is it possible to use this method when the turns and weights of wire in the two windings of a capacitor motor are not equal? (Note: (1) Kingsley of MIT replied to this question; (2) A professor from Rhode Island State asked what was being taught at

present, the revolving field or cross-field theory of single-phase motors; (3) Kingsley said that at MIT, they were teaching the revolving field theory exclusively; (4) Karapetoff, of Cornell, implied in a discussion that these methods of calculating capacitor motors were based on superposing 2 separately revolving fluxes, and that there was danger of inaccuracies due to saturation effects.)

1. The question as to whether the revolving field theory or cross-field theory should be used in single-phase motor analysis has been debated for many years. The engineers in our company are using both methods side by side in every day routine design problems, and I want to urge very seriously that neither method be allowed to drop out of the minds of men engaged in teaching.

For instance, the single-phase calculation method developed by C. G. Veinott and H. R. West, is based on the cross-field theory and is used by engineers of at least 4 large engineering companies. There are certain features that seem to be illustrated much more vividly than by the revolving field theory. On the other hand, such phenomena as the double-frequency rotor currents in a single-phase motor are not easily visualized by the cross-field method.

2. I think the authors of these papers on methods of calculating capacitor motors are to be commended, and I want to urge them as well as others, to keep working on this problem. There are now a number of different methods of attack, all of which can be used to calculate the performance. The principle difficulty now is the length of time involved. Those of us engaged in routine design need very badly a calculation method which is not appreciably longer than that which we use on single-phase motors. Our present method for polyphase motors involves 26 slide rule operations to calculate the performance for any given slip while the single-phase method takes 35 operations. The best I have been able to arrange any of the capacitor motor methods so far has been 107 operations. If we could cut this down to 40 or even 45, it would become very useful. This, of course, must be for capacitor motors where the two phases are not alike as we very seldom use equal windings.

3. I believe the inaccuracies due to saturation are not very serious due largely to the primary impedance dropping the induced voltage and the flux as the slip is increased. In any case, we need a method and it would be useful even with some error due to saturation.

G. F. Tracy (University of Wisconsin, Madison.): Reed and Koopman have used the expressions developed in their paper in order to predict the torque, currents, and voltages of a 3-phase motor operating as a capacitor motor at all slips from standstill to synchronous speed. From a practical standpoint the values of torque and line current at standstill are most significant, since these values determine the practicability of such a method for starting the motor. In a paper entitled "Split-Phase Starting of Three-Phase Motors," by Tracy and Wyss, in Electrical Engineering, October 1935, page 1068, expressions for torque and current similar to those in Reed and Koopman's paper were developed for the case of split-phase starting using a noninductive resistance in series with one terminal of the motor, and an inductive reactance in series with the second terminal; the third terminal being connected directly to the other side of the line. The expression for torque was further analyzed by differentiation to find the "best" values of resistance and reactance in terms of the constants of the motor; i.e., that pair of values which will produce maximum starting torque (equation 22 in Tracy and Wyss' paper). A similar analysis of the companion case using a resistance and a capacitive reactance was subsequently carried out by J. W. Soule, graduate student at the University of Wisconsin. The best value of resistance was found to be zero in all cases (actually slightly negative); while the best value of reactance was shown to be given by the surprisingly simple and valuable expression $X_c = 1.5z$, where X_c is the value of capacitive reactance in ohms and z is the value in ohms of the equivalent impedance per phase of the motor at standstill, motor assumed Y-connected. The validity of the above expression was verified in a series of tests by Soule; and it is also interesting to observe that when applied to the $^3/_4$-horsepower motor in Reed and Koopman's paper this expression yields a value of capacitance of 245 microfarads, whereas figure 8 of the paper shows the maximum starting torque to occur at 240 microfarads. In the case of the 5 horsepower motor, Reed and Koopman do not show starting torque as a function of capacitance. The best value of capacitance according to the above expression is 690 microfarads; i.e., more than 4 times as large as that used in the curves of figures 5–7. Had the value of capacitance used in their tests been 690 microfarads instead of 160 microfarads the starting torque would have been 150 per cent of the 3-phase starting torque instead of approximately 13 per cent as in figure 5. The starting torque corresponding to the best value of X_c is readily computed from $T = 28.8\, r/(z - x)$, where T is in per cent of 3-phase starting torque, and r, z, and x are respectively the numerical values of the resistance, impedance, and reactance, in ohms per phase of the motor at standstill, motor assumed Y-connected.

In general, the starting torque obtainable with an inductive reactance and a resistance connected as described above does not exceed 20 per cent of 3-phase starting torque even with the best values used for the resistance and reactance. It is a relatively inexpensive method, however, and is thus adaptable to large machines. On the other hand, the torque obtainable with a condenser only (as in sketch C of Reed and Koopman's paper) is of the order of 100 per cent of 3-phase starting torque. This means that a 3-phase motor operating from a single-phase line and started as a capacitor motor has starting characteristics comparable with those of a repulsion-start single-phase motor or those of a 3-phase motor. The over-all cost, however, is greater than that of a repulsion-start motor at the present price of condensers.

The authors make the statement in the opening paragraph of their paper that their method is "quite different from those which have appeared in the recent literature." The writer would like to state that it appears to him that the procedure used by the authors in treating the 3-phase motor operating single phase and also the 3-phase motor on unbalanced 3-phase supply is essentially the same as that used by O. C. G. Dahl in his book "Electric Circuits, Theory and Applications," volume 1, and also by C. F. Wagner and R. D. Evans in their book "Symmetrical Components." Also the authors' procedure in handling the case of the 3-phase motor operating as a capacitor motor does not appear to differ fundamentally from that used in the paper by Tracy and Wyss quoted at the beginning of this discussion, together with the discussion of this reference by E. M. Sabbagh (in Electrical Engineering, March 1936, page 285).

H. R. Reed and **R. J. W. Koopman:** Reeves' treatment of the induction motor operating on 4-wire 3-phase with one line open is interesting, especially since this point was raised in oral discussion by Karapetoff. This is not a common method of operating induction motors, and the problem of determining the impedance to zero-sequence current which would flow under these conditions should be of interest. Wagner and Evans in the December 1929 issue of the *Electric Journal* discuss this problem.

The statement by Selby Haar that unbalanced voltages in a polyphase supply system may be a serious matter has been considered by the writers from the point of view of decreased efficiency, in an article in a recent issue of *Electrical World*.

Tracy states that the "best" value of capacitance to have been used in the illustrative curves of figures 5–7 is that which produces maximum torque at starting. In the Tracy and Wyss paper referred to, however, the authors, using inductive reactance starting, state that "By 'best' values of R and X is meant that pair of values which will produce maximum starting torque—or, if such values should be accompanied by an excessive line current, the 'best' values would then be those which produce maximum torque at an arbitrarily fixed line current."

It would seem that the best value of capacitance to be used at starting should be that which would most nearly duplicate 3-phase conditions at the motor. It can be shown that for 3-phase motors with 3-phase

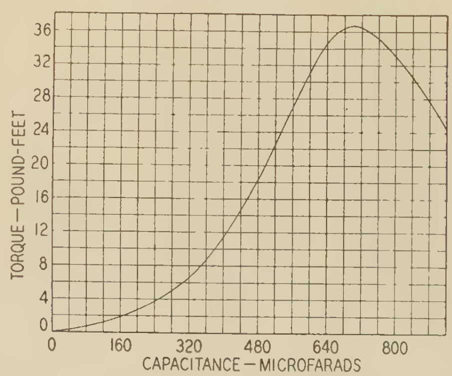
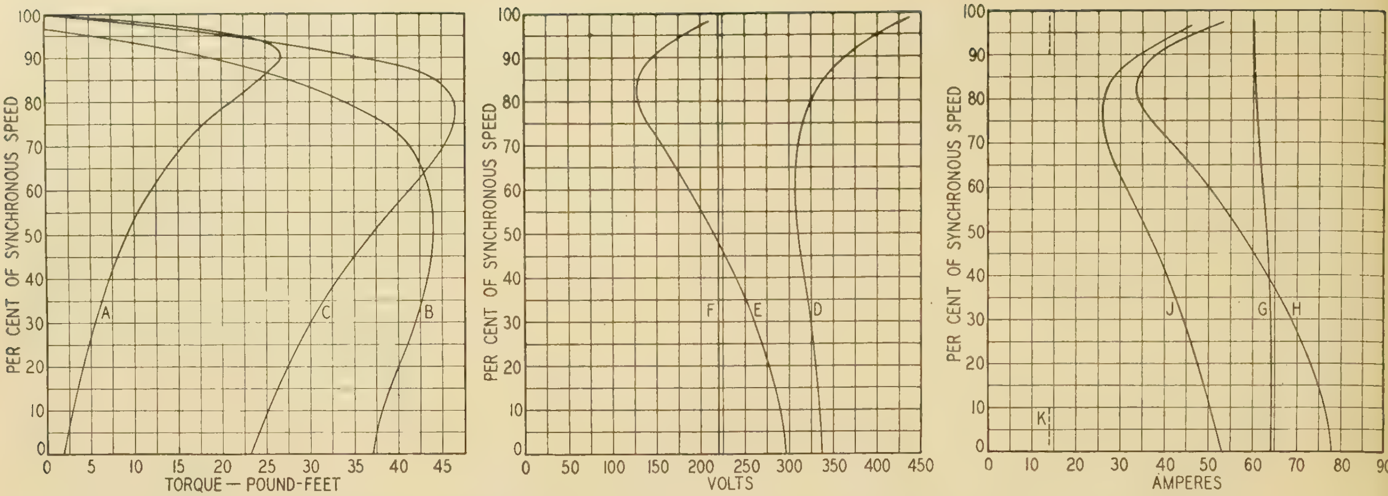


Fig. 5. Starting torque-capacitance characteristic for 5-horsepower 3-phase motor starting on single-phase supply as capacitor motor



Figs. 6–8. Characteristics for 5-horsepower 3-phase motor operating on single-phase supply as capacitor motor

A—Torque, single phase with 160-microfarad capacitor
B—Torque, single phase with 700-microfarad capacitor
C—Torque, 3 phase
D—Terminal voltage V_{ab}
E—Terminal voltage B_{bc}
F—Terminal voltage V_{ca}
G—Current I_a
H—Current I_b
J—Current I_c
K—Rated full-load 3-phase current

starting power factors less than 0.5, exact 3-phase conditions can be reproduced starting single-phase with a capacitor and a series resistor of proper size connected between the free terminal and one line. This resistor should have zero resistance if the 3-phase starting power factor is 0.5. Likewise it can be shown that for 3-phase starting power factors greater than 0.5, exact 3-phase conditions can be duplicated by placing an inductance of proper size between the terminal connected to the condenser (now without a series resistor) and the other line.

The relationship between starting torque and capacitance in microfarads for the 5-horsepower 3-phase 220-volt motor considered in appendix II of the paper is given in figure 5 of this discussion. The curve shows that the maximum starting torque is obtained with 700 microfarads capacitance; applying the expression $X_c = 1.5z$ gives 705 microfarads. The starting torque with 700 microfarads is 160 per cent of normal 3-phase starting torque; but the terminal voltages are 337, 296, and 220 volts, or 153, 135, and 100 per cent, respectively, of rated terminal voltage, and the coil currents are 78, 64, and 53 amperes, or 557, 457, and 379 per cent, respectively, of rated full load current.

Figure 6 is a comparison of the speed-torque curves when the motor operates 3 phase, single phase with the 160-microfarad capacitor, and single phase with the 700-microfarad capacitor. The relationships between the terminal voltages and the coil currents and per cent of synchronous speed are shown in figures 7 and 8 when the motor operates with the 700-microfarad capacitor. These curves show that when the motor operates with the 700-microfarad capacitor at 5 per cent slip it develops only 25.7 per cent of 3-phase torque at the corresponding slip, while the 160-microfarad capacitor it develops 108.5 per cent 3-phase torque. Figures 6 and 7 of the paper show that at this value of slip the currents and voltages are essentially normal whereas figure 7 of this discussion shows that the voltage V_{ab} is 181 per cent of normal. The coil currents from figure 8 are seen to be 429, 339, and 307 per cent rated full load. It is also of interest to note from figure 6 that the no-load slip when operating with 700 microfarads is 3.5 per cent and that the above-named 3-phase torque is produced at a slip of 11 per cent.

In view of the foregoing discussion it would seem to be uneconomical to use a large capacitance, which would cause excessive coil currents to flow and which in itself would have to carry a large current as is shown in the preceding curves. In choosing the value of 160 microfarads to be used in the tests the writers were desirous of obtaining a value of capacitance which would give to the motor operating characteristics which were essentially normal. To obtain such characteristics it was obviously impossible to obtain a high starting torque. In practice, the motor would be started using that value of capacitance which would either give ample torque to start the load or most nearly duplicate 3-phase conditions and as the machine comes up to speed the capacitance would be reduced to a value which gives normal operation. The "best" value of capacitance to use in starting this motor would obviously not be that which produces the maximum starting torque as Professor Tracy indicates in his discussion, and that value would certainly not be used over the working range of the motor.

The expression $X_c = 1.5z$, which gives the value of capacitive reactance to produce maximum starting torque is noteworthy, as is likewise the expression which yields the per cent of 3-phase starting torque.

The writers are cognizant of the fact that the fundamentals are similar to those used by Dahl, Wagner, and Evans, and others. In considering the 3-phase motor operating single phase, Wagner, and Evans combine the sequence networks in an entirely different manner. The paper by Tracy and Wyss deals only with the inductive method of split-phase starting of 3-phase motors and considers neither the capacitor motor nor speed-torque curves, the accurate prediction of which the writers believe to be of paramount importance.

With reference to Trickey's question concerning operation with unequal windings we would refer to reference 3, "Analysis of Unsymmetrical Machines," by Lyon and Kingsley, AIEE Transactions, volume 55, May 1936.

In the oral discussion the question of saturation was raised by Karapetoff. The writers believe that this question is adequately answered in the discussions of Corcoran and Trickey.

Lightning Investigation on Transmission Lines—VI

Discussion and authors' closure of a paper by W. W. Lewis and C. M. Foust published in the January 1937 issue, pages 101–6 and 189, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 26, 1937.

J. J. Smith (General Electric Company, Schenectady, N. Y.): During the last 10 years much work has been done on the problem of lightning interruption of electric-power service and now insulation and protection can be arranged in most cases to reduce tripouts to a very small number. While this progress is due to a number of circumstances it is nevertheless quite outstandingly evident from a survey of recent literature that an important factor has been the introduction of practical measuring instruments for direct connection to the transmission line. At the time the present investigation began there were available almost no direct measurement data which assisted toward an understanding of the problem.

Into this situation was introduced the Lichtenberg figure cameras such as the klydonograph, surge-voltage recorder, and lightning-stroke recorder. All these provided for the measurement of crest values of surge voltages and the determination of

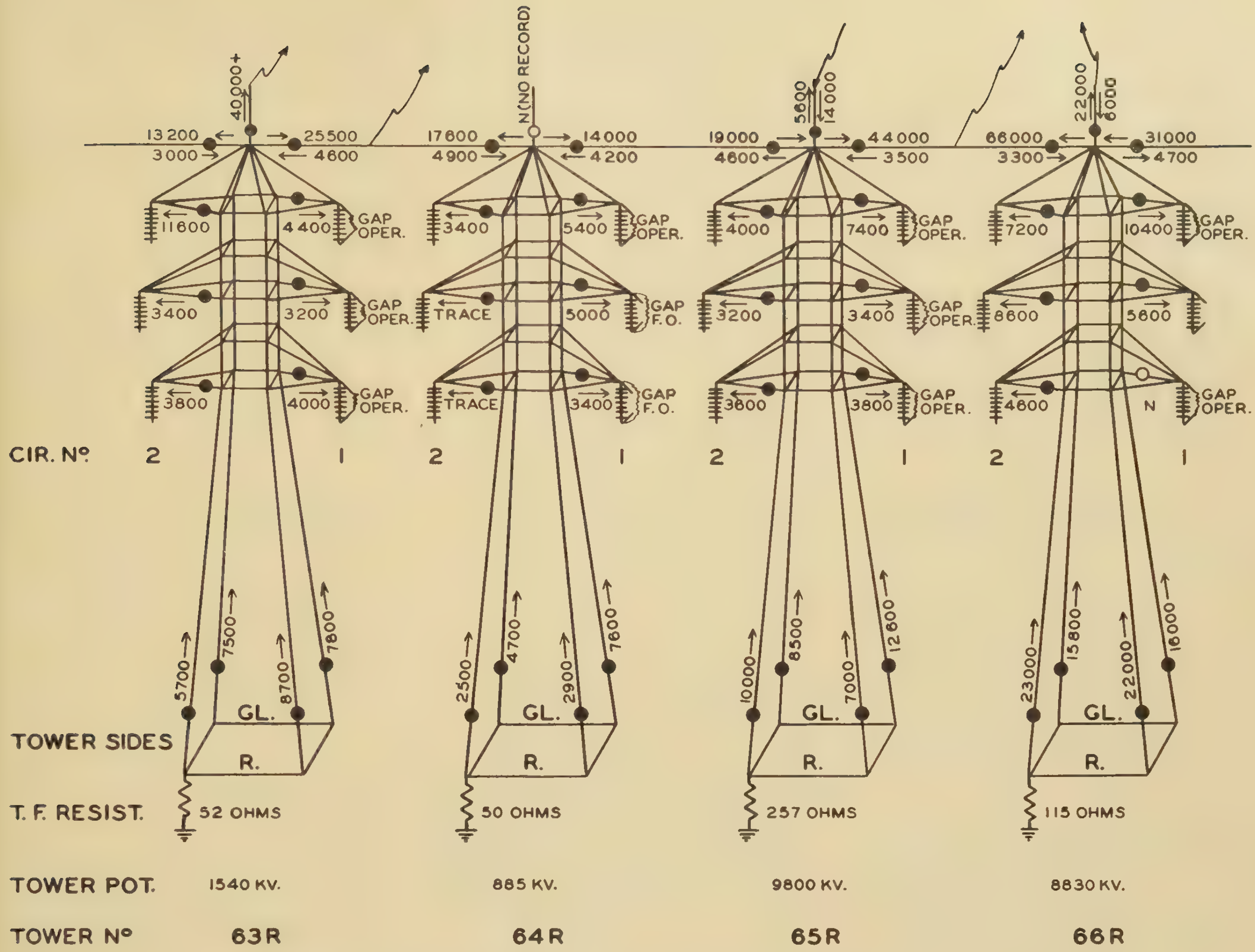


Fig. 1. Lightning currents measured in towers of 132-kv Glenlyn-Roanoke line, May 4–15, 1936

polarity. Conductor and structure potentials were then obtained by the hundreds. Lightning surges were followed along the conductor and attenuation directly measured. The Lichtenberg camera as a surge-voltage recorder therefore served to redirect the attack on the tripout problem, to take it away from the desk and laboratory and to concentrate effort on the task of requiring the lightning surge to locate and describe itself through the medium of such recorders.

The surge indicator or flashover indicator followed the surge recorder. This was a device which through the disruption of a small breakable powder link provided an indication of insulator assembly flashover until the patrolman observed it from the ground and reset it for the next flashover. Again many indicators, several thousand in fact, were used and hundreds of insulator flashovers and surges recorded.

The cathode-ray oscillograph was also applied to the measurement of lightning-surge wave shapes on line conductors. The elaborate equipment and somewhat complicated technique of operation required permitted the use of only a few oscillographs. Many valuable wave-shape records were obtained, however, among them one of conductor potential at a point within a few feet of a direct stroke.

All the instruments up to this time were used to obtain information concerning voltage conditions. The accumulating records, however, directed attention toward the necessity for lightning-current measurements and out of this need came the surge crest ammeter. Measurement stations again were established by the thousands. Entire lines were covered and many locations in the line structure such as tower legs, tower arms, overground wires, lightning rods, counterpoise and occasionally even the live conductor. Thousands of records were obtained and these when fitted in with the records from earlier instruments provided a greatly clarified picture of the lightning tripout problem. It is a thoroughly different picture from the previous desk-laboratory picture common at the beginning of the investigation, and this difference is mainly due to the devising of suitable recording and low cost, indicating and measuring devices through which the lightning surge has located and described itself automatically.

Table I of the paper gives an interesting comparison of the tripouts per 100 miles per year on different lines. Some of the differences are due to changed conditions on the same line over a period of years. However, for lines in different localities it is difficult to make a direct comparison since there must exist differences in the lightning conditions experienced. I wonder if the authors can suggest a way of taking these differences in lightning conditions into account.

On page 103 the authors show good correlation between the measurements when voltage exceeded flashover of the insulators and actual flashover. It is not quite clear, however, whether they have experienced flashover in cases where the measured voltage was well below that required. I should like to know their experience in this respect.

Philip Sporn (American Gas and Electric Company, New York, N. Y.): This paper is devoted in a large part to presentation and discussion of the field data obtained in the research and investigation that has been carried out over the past 4 or 5 years on the Glenlyn-Roanoke 132-kv line of the Appalachian Electric Power Company. However, the period covered by Lewis and Foust deals almost entirely with records obtained prior to 1936. Some of the most interesting data were not obtained until the year 1936, and in view of the fact that it was not found possible to present these data in summary form at this meeting of the Institute, owing to the shortness of time, it may be interesting to give some of the high lights of the 1936 investigation, and particularly those that bear directly on, and tie in with, the data presented by the authors of this paper.

In figure 2 is shown the magnitude and frequency of lightning stroke currents

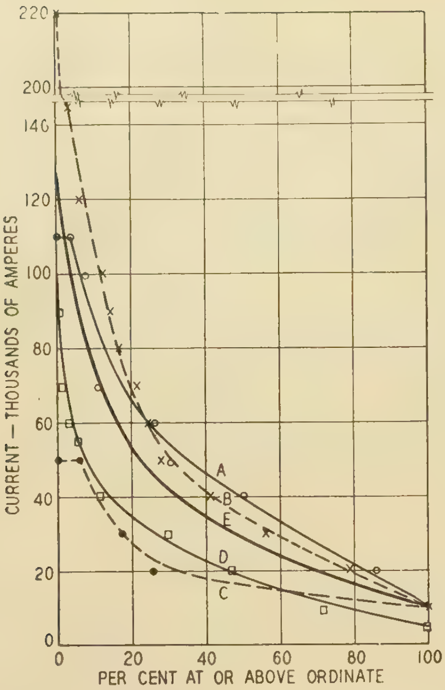


Fig. 2. Magnitude and frequency of lightning stroke currents, 1933–36

A—By ground-wire currents
B—Sum of adjacent tower currents
C—By tower-top lightning rods
D—Single tower currents
E—Average of *A*, *B*, and *C*

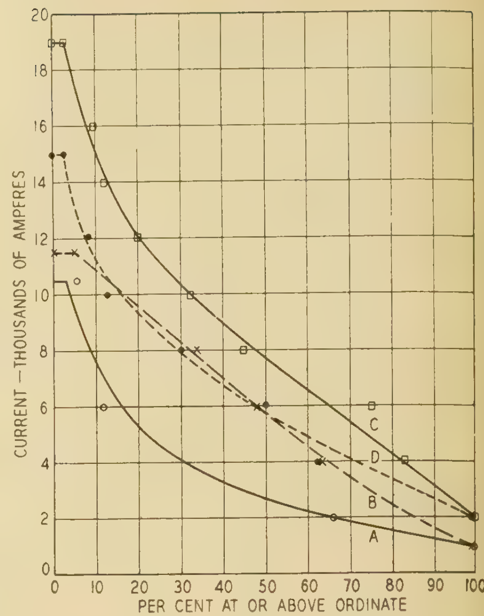


Fig. 4. Relation between currents in tower leg and attached counterpoise on Glenlyn-Roanoke line, 1934–35–36

A—Short counterpoise
B—Short-counterpoise tower leg
C—Long counterpoise
D—Long-counterpoise tower leg

measured in the field by 3 different methods namely, currents in the ground wire, by addition of adjacent tower currents, and by direct measurement in tower-top lightning rods. While the current values recorded in this manner show some spread, the average of the 3 curves gives what is believed to be a fair representation of conditions which may be encountered in the field.

A considerable part of the investigation centered around the measurements of lightning currents in counterpoise wires. Figure 3 shows graphically the flow of current along the counterpoises, the counterpoise arrangement being shown in the upper right-hand corner.

The current in the long (150-foot) counterpoise is on the average 4 times the current in the short (40-foot) counterpoise, as measured at the point where connected to the tower. At the free, distant ends the currents are about equal in both. Uniform leakage of current from the long counterpoise is indicated by the averaged data. Clearly the long counterpoise is much more effective than the short one in draining current to ground. Other data, not presented here, indicates the short counterpoise behaving much like a plain ohmic resistance, while the long counterpoise displays an ability to carry current in excess of expectations on the basis of its d-c resistance alone.

An interesting relation between the current in the tower leg and connected counterpoise is shown in figure 4. It might be expected the current in any counterpoise would be less than the tower leg to which it is connected. However, it will be seen this was found to be true of the short counterpoise; but the reverse was true for the long counterpoise, where in some cases the long counterpose at the tower end carried some 30 per cent more than the tower leg. The reason for this has as yet not been fully explained.

Typical field records on which the correlation and interpretation of data were based are shown schematically in figure 1. One interesting feature of this record is the 66,000 amperes found in the ground wire associated with an apparent lightning stroke of 110,000 amperes to the line. Another feature is suggestive of a branched lightning stroke terminating at 2 adjacent towers and also midspan between them. These may, of course, be separate strokes during the same or different storms.

Still another feature of this one record is the high indicated tower potentials at the 4 adjacent towers, 2 of them being 9,800 kv and 8,830 kv, respectively, these being calculated on the basis of tower footing resistance and tower leg currents. Line flashover occurred at all 4 towers, as might be expected.

All this work is particularly interesting from the standpoint of showing what can be accomplished once measurements in terms of fundamental units, and particularly in terms of units of potential and current, are initiated. The great progress made in understanding the lightning phenomena is due in no small degree to the measurement of currents that have been made over the last 3 years under natural lightning conditions, and these in turn as this paper, and as I hope the brief discussion just given has brought out, have been directed more and more toward a detailed study of the various parts of the lightning circuit and an attempt to trace the lightning current from the time it discharges from the cloud until it definitely completes the circuit to ground, and all the current in the various parts of that circuit are accounted for.

A great deal more data along this line were obtained in last year's work on the Glenlyn-Roanoke line. A much more complete summary of some of this data, it is expected, will appear in an early issue of Electrical Engineering.

L. V. Bewley (General Electric Company, Pittsfield, Mass.): In these papers there is the implication that the counterpoise "collects current" or "drains charge" throughout its length. Lewis and Foust, from measurements on 150-foot and 40-foot counterpoises arrive at a *uniform* collection per foot, but Bell shows records over several spans on continuous counterpoises of very irregular collection of current. The authors apparently do not regard the action as a simple traveling wave phenomenon, but rather as a *diffusion* of current up from the ground and along the counterpoise to the tower. That is, instead of a *negative* wave coming down the tower and moving out along the counterpoise, there is a veritable suction of *positive* charge up out of the earth which flows—but not as a wave—toward the tower and on up the lightning stroke to the cloud. Lewis and Foust speak of an essentially uniform potential along the counterpoise, and the natural inference is, then, that the counterpoise behaves merely as a concentrated resistance, presumably equal to its leakage resistance to earth. If

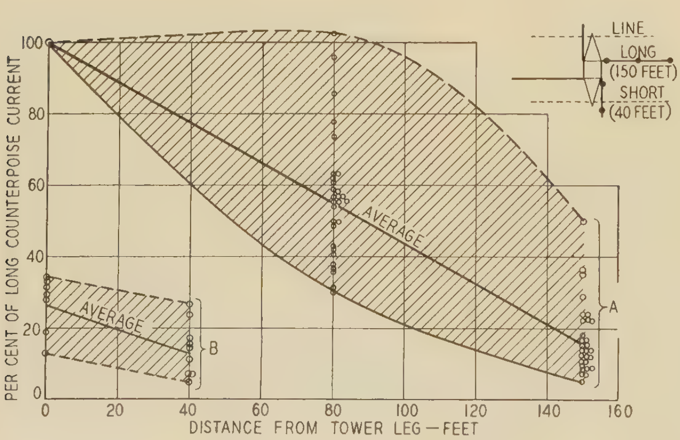


Fig. 3. Attenuation of lightning currents in counterpoises on Glenlyn-Roanoke line, 1935–36

A—Long counterpoise (30 records)
B—Short counterpoise (9 records)

this were so, it would make no difference whether a mile of wire were employed as one long counterpoise, or as many short ones in multiple. Moreover, a sufficiently low leakage resistance would be the only criterion for a counterpoise. For these reasons it seems to me somewhat dangerous to adopt such a point of view; at least until the traveling wave point of view has been found incapable of explaining the results. I therefore wish to demonstrate that the records obtained by the authors are in no wise contrary to ordinary theory and tests on the counterpoise.

It has been shown [1,2,3,4,5,6] both by theory and by field tests that the action of a counterpoise is essentially characterized by 3 effects:

1. The transient surge impedance starts at an initial value of 150 to 200 ohms and decays in a roughly exponential fashion to a final value equal to its leakage resistance.

2. The velocity of propagation is approximately $1/3$ the velocity of light, and due to the heavy attenuation, a single reflection is sufficient to equalize a given length of counterpoise, so that a length x is reduced from its initial surge impedance to its final leakage resistance in a time in microseconds equal to 6 times its length in thousands of feet.

3. The coupling with overhead conductors is of minor importance, amounting to less than 10 per cent for a parallel counterpoise.

Assume that a traveling wave E comes down the lightning stroke of surge impedance Z_0 and strikes a tower having a counterpoise of transient impedance $Z(t)$. Then according to elementary theory, the voltage and current of the counterpoise are, respectively

$$e = \frac{2\,Z(t)}{Z(t) + Z_0} E$$

$$i = \frac{2}{Z(t) + Z_0} E$$

Obviously, the counterpoise voltage e, and therefore the tower top voltage, is a maximum in the neighborhood of the crest of E, but the counterpoise current i does not reach its maximum until later. If E were a moderately long wave, i would not reach its maximum until $Z(t) = R$, where R is the final, or leakage, resistance of the counterpoise. Now a surge crest ammeter merely measures the maximum current; and as is evident above, this maximum current *does not coincide with maximum voltage*, because the counterpoise impedance is changing. In other words, the leakage resistance of the counterpoise is not available at the instant of maximum voltage, and therefore the tower voltage will exceed the RI of the counterpoise. The point is illustrated in figure 1, when a 10,000-kv lightning wave with a 1.5-microsecond front strikes a counterpoise. For simplicity the ground wires and tower footing resistance are neglected. The 500-foot counterpoise transient impedance falls from 200 ohms initially to 20 ohms finally in 6 x 500/1,000 = 3 microseconds. By the equations, the voltage is seen to reach a maximum of 2,600 kv at 1.0 microsecond while the current does not reach its maximum of 46,000 amperes until about 2.0 microseconds. If this maximum current were multiplied by the leakage resistance of the counterpoise the result of 920 kv would only be $1/3$ the actual maximum voltage.

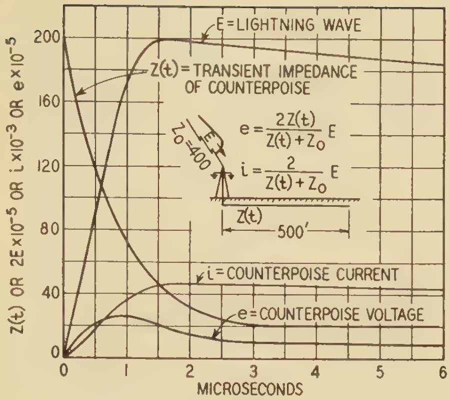


Fig. 5

This also explains why the IR products are usually too small to account for the flashovers known to have occurred, especially in view of the fact that the voltage across the insulators is actually

$$V = (1 - \text{coupling factor})RI$$

and the coupling factor will be from 0.20 to 0.40.

Thus it appears that the observed results are in full accord with the ordinary traveling wave theory and tests of the counterpoise. Nor does the available surge crest ammeter data in itself offer any plausible reason for changing to a "diffusion" theory yielding a very much smaller voltage. It may be remarked, however, that the longer the wave front the more nearly do conditions approach the leakage resistance conditions of the counterpoise, but this is a natural result of wave theory and in no wise a substitution of mechanism.

References

1. Experimental Studies of Lightning Surges on Transmission Lines, O. Brune and Eaton. AIEE Transactions, volume 50.

2. The Counterpoise, L. V. Bewley. *General Electric Review*, February 1934.

3. Counterpoise Tests at Trafford, C. L. Fortescue. Electrical Engineering, July 1935.

4. Theory and Tests of the Counterpoise, L. V. Bewley. Electrical Engineering, August 1934.

5. Discussions by J. H. Hagenguth and L. V. Bewley, Electrical Engineering, February 1935.

6. Fixing Counterpoise Length, L. V. Bewley and J. H. Hagenguth. *Electrical World*, March 2, 1935.

S. K. Waldorf (Pennsylvania Water and Power Company, Baltimore, Md.): Lewis and Foust present additional evidence that lightning difficulties can be practically eliminated by the use of overhead ground wires and counterpoise. The experience of the Pennsylvania Water and Power Company shows very markedly the efficacy of these lightning protective measures. The Safe Harbor - Westport - Takoma 230-kv. line passed through 1936 without a single outage, making the record of this line only one outage in 5 years. Also the Safe Harbor-Perryville 132-kv line has passed through its second year of operation without any outages occurring in its lifetime.

Of particular interest has been the experience with the Holtwood-York 69-kv line which is a double-circuit steel-tower line having 2 overhead ground wires and a double continuous counterpoise system. Formerly, this line had no overhead ground wires nor auxiliary grounding. Tower footing resistances ranged from 17 to 525 ohms, with an average of 133 ohms. Its operating record was particularly bad, having an average of 19.3 single- and double-circuit outages per year in the 6-year period, 1929–1934, inclusive. After the counterpoise was installed, the maximum tower-footing resistance became 20 ohms, with the average value at 9.2 ohms. In the $1^1/_4$ lightning seasons since the lightning protection has been added, there have been no outages. This record is worthy of special notice because it indicates that tower lines operating at as low as 69 kv in high-resistivity territory can be made to behave well with counterpoise and overhead ground wires.

P. L. Bellaschi (Westinghouse Electric & Manufacturing Company, Sharon, Pa.): These investigations clarify further the lightning behavior on transmission lines particularly the current distribution in the ground-wire network, the towers and the counterpoise. Perhaps there may be the impression that rather complete data are now available on the lightning protection problem. Practically speaking this viewpoint is correct in a good measure. That more need be known on the lightning

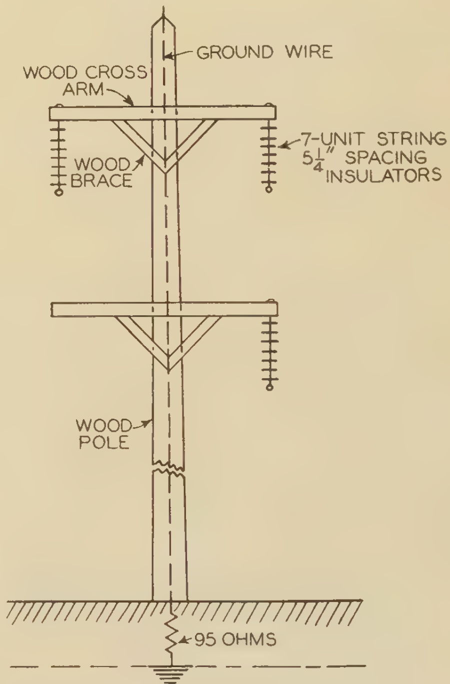


Fig. 6

phenomena even at this advanced stage need hardly be emphasized. I shall illustrate with an example which is rather typical of similar experiences encountered in the study of lightning.

Lightning struck the top end of a wood-pole ground wire (figure 1). Due to the high voltage resulting from the lightning current through the driven ground, flashover occurred from the ground wire to each of the 3 phase conductors. No indication of

flashover was observed at the adjacent poles.

Judging from the data on wood and insulators alone, the voltage time-lag curve for the combined insulation would be quite flat from the full wave (1.5x40 microsecond) down to a few microseconds and essentially the same for positive and negative polarities. Refinements are unnecessary for the purposes here. The estimated strength for the wood cross-arm and the insulator string (figure 1) is in the order of 1,400 kv. Though the resistance of the driven ground at the pole as measured by ordinary methods is 95 ohms, the effective surge resistance when a lightning current discharges through it would be some $^3/_4$ that amount (see for example discussion by Lewis and Foust, ELECTRICAL ENGINEERING, March 1936, page 279). The surge impedance of the 3 lines in parallel is approximately 200 ohms. The accuracy of all these figures are within practical tolerance—amply adequate for this example. The effective impedance from the wood pole-ground wire to zero-potential earth calculates in the order of 40 ohms. The coupling factor between the ground wire and the line conductors is rather small.

By token of the same methods as employed in the investigations here discussed and in other important work, the maximum current associated with the stroke in question is estimated to have been in the order of 50,000 amperes.

Consideration of all the available evidence reveal additional, pertinent information. The tip end of the wood pole ground wire which was struck by the lightning stroke was studied. This is a number 4 soft-drawn copper wire, i.e., 0.20-inch diameter. The tip end was fused and the molten metal flowed down the sides a length equal about the diameter. Evidence of overheating extended down a length of a few diameters. Tests were conducted in the laboratory on a similar conductor. Lightning currents from 50,000 to 100,000 amperes (approximately) and of a total duration of 100 microseconds were applied at an interval apart (2 minutes approximately) sufficient for the tip end of the conductor to cool down between applications. These tests indicate that $^1/_8$ inch of the tip down the side was raised near or to fusion temperature. Besides the oxydized surface extended downward some $^1/_2$ inch.

A close comparison of the field specimen and the samples tested in the laboratory lead to the following conclusions: (*a*) A repetitive stroke consisting of some 3 or 4 discharges apparently hit the conductor; (*b*) The maximum current in the discharges appears to have been in the order of 50,000 amperes.

The data pertaining to figure 4 in a paper by the writer (ELECTRICAL ENGINEERING, August 1935, page 839), similar information of the kind and the recent experiences abroad (Norinder in Sweden) further strengthen the conclusions above.

The case here described would appear to be similar to the 2 cases indicated as items 11 and 12 in table III of the paper by Lewis and Foust. Measurements with the crest ammeter would undoubtedly have contributed information on the crest value of the current but, as in the 2 cases in table III, no information on the "time factor"—an important element in lightning studies. It can be seen from this illustration and from similar cases that could be added that further methods of measurement and analysis than those employed in the investigations discussed are susceptible of giving additional, useful data on the lightning phenomena. This critique does not detract from the valuable contributions by Edgar Bell and Lewis and Foust.

W. W. Lewis and **C. M. Foust:** The authors wish to thank all those who have contributed discussions. J. J. Smith asks about the tie-in between lightning severity at particular locations and tripouts per 100 miles per year as given in table I of the paper. In course of this investigation, lightning-severity meters have been used at several locations over a period of a few years' time. The conclusion reached from their use was that severity does vary greatly at any particular location from year to year. It was not found possible to tie in the severity meter results closely with line performance, particularly because the latter depended so much on line construction. The most interesting scientific information on lightning frequency is obtained with the ceraunograph. These are electromagnetic instruments used by the weather bureau and through which the whole country is marked out in isoceraunographic lines of equal thunderstorm frequency. The transmission lines in table 1 extend over a territory from Albany, N. Y., to Washington, D. C., across New Jersey, eastern Pennsylvania, Maryland, and Virginia. The thunderstorm-frequency average ranged from no thunderstorm days in January to 150 to 200 thunderstorm days in July. The northern end of this territory has an average of about 45 storms per year and the southern end 55 from isoceraunograph records.

Smith also asks if flashovers have been experienced in cases where tower potential is well below that required. There are, according to the best analysis possible, several of such cases, but the preponderance of flashovers are co-ordinated with high tower potentials, and it is on this basis that the conclusions are drawn. It must be borne in mind at all times with regard to such data that correlation of flashover with a current record is never direct and positive unless by chance observation. Where automatic oscillographs are used to locate flashover, a strong evidence of tie-in is obtained, otherwise it is necessary to consider operator's reports, storm data, insulator inspections, tube performance, as well as current records in arriving at a correlation. It is to be expected that occasionally incomplete records do result in wrong correlation. However, these are infrequent, but may explain some of the few correlations of low tower potentials with flashovers.

In Philip Sporn's interesting discussion, attention is called to the case where the long counterpoise carried some 30 per cent more current than the tower leg to which it was attached. The explanation has been advanced that this is due to high currents in cross tower members, occasioned by the unsymmetrical counterpoise arrangement used.

Referring to L. V. Bewley's discussion, the term "diffusion" as a name for the lightning mechanism is inappropriate. We like to call it the Ohm's-law theory if a name is required. True, we do not regard the phenomena as a negative wave coming down the tower, nor do we regard it as a "veritable suction of positive charge up out of the earth." It is considered that, for the main stroke, current flows from the positive potential ground to the negative potential cloud. This conception is the common one of a current flowing from positive to negative. It is realistic to regard the counterpoise as practically at uniform potential in so far as flashover voltages are concerned. The counterpoise resistance to earth, however, is not a "concentrated resistance," but exactly the opposite, a distributed one and low because of it and that is just why it serves its purpose of holding down tower potential. Only by spreading out the conducting earth terminal by such wires at the tower footings is there deliberately achieved a decrease of tower-to-ground resistance. Comparing the extreme of a mile of single counterpoise to a number of short ones in multiple has no practical significance as the condition is not realistic. The sum total effect required is that of reducing the "across ground" voltage drop by reducing ground resistance which is highest immediately at the tower footings. Such a reduction in footing resistance shifts the ground potential up into the air arc.

Pertaining to Bewley's demonstration that records obtained are in no wise contrary to theory and tests on the counterpoise, it is regretted that the proof is not more convincing. Artificial lightning field tests are not particularly interesting in connection with such a proof. These are concerned with a quite different phenomenon from that of natural lightning. A 10,000-kv lightning wave with a 1.5-microsecond front striking a counterpoise is quite imaginary. The coupling factor of 0.2 or 0.4 may be correct or not, it should be measured and quite likely will in process of these investigations. The *IR* products of footing resistance and current are not usually too small to account for flashover, in fact the reverse is true, as we have pointed out, and these potentials are usually high enough to account for flashover.

Bewley's closing sentence is interesting and it is suggested that he consider carefully longer wave fronts, particularly those very slow in building up at the start, and then more rapidly as time increases.

Mr. Waldorf's discussion is valuable in that it calls attention to the usefulness of counterpoise and overhead ground wires as demonstrated by several cases of actual operational experience.

Electrical Characteristics of Suspension-Insulator Units

Discussion and authors' closure of a paper by C. L. Dawes and Reuben Reiter published in the January 1937 issue, pages 59–66, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 26, 1937.

W. M. Goodhue (Harvard University, Cambridge, Mass.): The curves obtained by the authors are remarkable in involving linear relationships, and particularly in

using *absolute* humidity instead of relative humidity as the variable. As is well known, the moisture content (including adsorption as in vegetable fibers, glass surfaces, etc.) of materials is not related to the absolute humidity, since materials tend to evaporate their moisture when the temperature is raised, just as water itself evaporates more at a higher temperature. Evidently some mechanism other than the moisture itself, but dependent on the moisture and *temperature*, is acting to counteract the effect of relative humidity.

The authors suggest that the island deposits are sputtering of the pin or cap metal in conjunction perhaps with chemical action. It would be important to know the effect of temperature on this action. A large increase of action with temperature increase would compensate the effect of temperature in reducing the relative humidity, when the absolute humidity is constant, and thus make absolute humidity the nearest significant variable, as it has been shown to be experimentally. A new avenue of experimentation would be to study corona sputtering itself, over a wide temperature range (say 20 degrees to 100 degrees centigrade), with temperature and absolute humidity as variables; something very practical may result from a *pure scientific investigation* of corona sputtering.

Time lag or hysteresis in corona measurements have doubtless been noticed in many types of apparatus. Some measurements that I made on *flat uniform dry air films* involved time lag. Evidently the authors have revealed new causes of hysteresis, so that in insulator work we have now a very large list: corona itself (electrical action), composition of the surrounding atmosphere (chemical change), *sputtering* (*islands*, surface action), heat (due to power loss), humidity (moisture acting merely as surface conductor), etc.

M. G. Malti (Cornell University, Ithaca, N. Y.): The results of this excellent paper recall to mind similar curves obtained on various insulating materials, as early as 1893, by Janet,[1] Potter,[2,3] Morris,[2,3] and others.[4-12] Many writers[12-18] have observed a hysteresis effect in the resistance of dielectrics with varying voltage gradient,[14,15] varying temperature,[13,18] varying mechanical pressure [15] and varying humidity.[17] The dielectric permittivity is also known to reveal a hysteresis effect with voltage gradient[19] and with temperature.[21,22] Finally the loss in dielectrics displays a hysteresis effect with temperature.[22,23] These are only a few of the many hysteresis effects that have been known to men interested in the study of dielectrics. The present paper adds the fact that porcelain and glass insulators display hysteresis effects in their loss, power factor, and capacitance when these are measured with varying voltage, varying mechanical pressure and varying degrees of humidity. These results are both interesting and significant. But I believe the authors could have laid more stress on the hysteresis and the hystero-viscosity phenomena in their interpretation.

It is impossible to interpret the hysteresis effects of figures 3 to 7 and 10 to 14 by the circuit figure 2 of the paper. This circuit owes its origin to Maxwell who used it as a model to interpret absorption and loss in

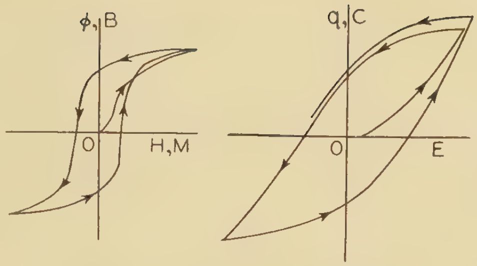


Fig. 1a (left). Magnetic hysteresis

Fig. 1b (right). Dielectric hysteresis

dielectrics. It served its purpose for a time. But very soon it became evident that dielecrics had properties which cannot be interpreted by such a simple model. This model has therefore been discarded and, to physicists, is now of historical interest only.

To interpret the results of this paper, as well as those of the researches mentioned in the bibliography, quantitatively would require an elaborate theory which we do not, at present, possess. A general qualitative interpretation, such as the authors have attempted, may be readily given on the assumption that dielectrics possess hysteresis just as magnetic materials do. In order to make this statement more real let us examine dielectric and magnetic hysteresis side by side to see the analogy.

In figure 1*a* is shown a magnetic hysteresis loop plotted with B against H which, by a change of scale, can be converted into $\phi = BA$ against $M = Hl$. Now, we engineers work directly with the B-H curve. We never say that such a curve can be imitated by a model consisting of a series-parallel combination of pure inductances and pure resistances. The hysteresis loop is sufficient unto itself, is accepted as a physical fact and dealt with directly with no intermediate models to obscure the facts or becloud the issue.

Dielectrics display a similar behavior as shown by this paper and references 1–12. Indeed figure 1*b* is taken from reference 12 and represents the charge Q plotted against the potential E. The hysteresis effect is unmistakable. Moreover, if we take the charge Q figure 1*b*, as corresponding to the magnetic flux ϕ (figure 1*a*) and the voltage E (figure 1*b*) as corresponding to the magnetomotive force M (figure 1*a*), the analogy becomes irrefutible and complete.

Now the phenomena described by the authors in their figures 3 to 7 are purely dielectric hysteresis phenomena and show a part of the hysteresis loop figure 1*b*. Indeed the capacitance curves figure 3 and figure 6 of the paper can be easily shown to be simply hysteresis loops similar to figure 1*b* of this discussion by the following simple transformation:

We know that $q = ce$. Hence for any e, q varies as c. Thus by merely changing the scale in figures 3 and 6 the curves c versus e may be changed to q versus e, which are, respectively, the abscissa and ordinate of the curve figure 1*b*.

One more word about this research. The authors have an excellent experimental setup but they have introduced so many variables that their work has lost much of its fundamental importance. It is well known[24] that the following factors affect the capacitance, loss, and power factor of a dielectric: (*a*) voltage gradient; (*b*) shape of voltage wave; (*c*) time of application of voltage; (*d*) frequency; (*e*) temperature; (*f*) mechanical pressure; (*g*) humidity; (*h*) ionizing radiation; (*i*) shape of material; (*j*) shape of electrodes; (*k*) material of electrode; (*l*) electrode area; (*m*) thickness of dielectric; (*n*) physical condition of dielectric; (*o*) chemical composition of dielectric; (*p*) ionizing radiations.

Several of these factors entered simultaneously into the research under discussion and no attempt was made to eliminate all but one factor. For this reason the results cannot be generalized and must be restricted, in their application, only to the conditions under which they were taken.

Bibliography

1. Hysteresis and Viscosity of Mica for Rapid Oscillations, P. Janet. *C. R.*, volume 116, page 373, 1893 and *J. de Phys.*, 3, 2, page 337, 1893.

2. Dissipation of Energy in Dielectrics, A. W. Potter and D. K. Morris. *Proceedings* of the Royal Society, 54, page 7, 1892.

3. On the Question of Dielectric Hysteresis, A. W. Potter and D. K. Morris. *Proceedings* of the Royal Society, 57, page 469, 1895.

4. Energy Loss in Dielectrics, P. Gasnier. *Electrician*, 36, page 7, 1895.

5. Solid Dielectrics, V. Cremieu and L. Malcles. *C. R.*, 39, pages 790–92, and 969–72, 1904.

6. Electric Properties of Porcelain, H. F. Haworth. *Proceedings* of the Royal Society, 81, page 221, 1908.

7. Viscosity of Dielectrics, J. Granier. *Review Gen. de L'El.*, volume 10, page 219, 1921.

8. Piezo-Electric and Allied Phenomena in Rochelle Salt, J. Valasek. *Physical Review*, series 2, volume 17, page 475, 1921.

9. Reversible Inductivity of Rochelle Salt Crystals, J. G. Frayne. *Physical Review*, 21, pages 348–59, 1923.

10. Dielectric Anomalies in Rochelle Salt Crystals, J. Valasek. *Physical Review*, 24, pages 560–68, 1924.

11. Dielectric Viscosity, J. Granier. *J. de Phys. et le Rad.*, 5, pages 51–8, 1924.

12. Dielectric Hysteresis and Allied Phenomena, H. Saegusa. Tohoku University Scientific Report, 10, pages 101–116 and 437–43, 1921.

13. Electric Resistance of Glass at Different Temperatures, Thomas Gray. *Phil. Mag.*, series 5, volume 10, pages 226–233, 1880.

14. Dielectrics, R. Appleyard. *Phil. Mag.*, 38, page 396, 1894.

15. Contact with Dielectrics, R. Appleyard. *Phil. Mag.*, 10, pages 485–497, 1905. *Electrician*, 55, pages 984–87, 1905.

16. Electric Properties of Porcelain, H. F. Haworth. *Proceedings* of the Royal Society, 81, page 221, 1908.

17. Characteristics of Insulator Resistance, S. Evershed. *I. E. E. J.*

18. Electrical Conductivities and Transition Points of Glasses, H. Schoenborn. *Zeits. Phys.*, 22, 5, pages 305–16, 1924.

19. Dielectric Constant of Mica in Intense Fields, H. H. Poole. *Phil. Mag.*, 32, pages 112–129, 1916.

20. Dielectrics at Low Temperatures, J. Curie and P. Compan. *C. R.*, 134, pages 1296–9, 1902.

21. Mica Condensers as Standards of Capacity, H. L. Curtis. Bureau of Standards Bulletin, 6, pages 431, 1910.

22. Measurement of Dielectric Loss by Compensated Wattmeter, G. B. Shanklin. *G. E. Rev.*, volume 19, page 842, 1916.

23. Dielectric Loss in Industrial Cables, G. Renneson. *Rev. Gen. de L'El.*, volume 7, page 579, 1920.

24. Solid Dielectrics, M. G. Malti. *Sibley J of Engineering*, volume 43, pages 137–41, 193–8, 243–9, 269 and 280, 1929.

Sidney Withington (New York, New Haven, and Hartford Railroad, New Haven, Conn.): This paper has developed insulator characteristics of much interest, and the authors are to be complimented for their contribution to this very important subject. It is to be hoped they will continue their tests, and that their work will inspire others.

It is apparent, as the authors have stated, that in the case of the 2 insulators tested, each, it is understood, rated at 18,000 pounds a definite change of some kind occurs in the porcelain insulator at approximately 8,000 pounds and in the glass insulator at about 12,000 pounds. Any such change, while undoubtedly very small in extent and observable only in the laboratory, nevertheless may be of considerable interest and *may* indicate some slight damage to the porcelain or cement connection.

The loads at which this change occurs may be within the range of loads imposed under service conditions, especially in the case of the porcelain insulator, when this point occurs at less than half the designed M. and E. stress. Even if, as intimated by the authors, the change is due only to some readjustment of the pin, the cement and the compound used for sealing, nevertheless if this readjustment is recurrent each time the stress passes this point, there may ultimately be serious deterioration.

It would be of much interest I believe to continue these tests with other types of insulators to determine whether or not this is a general characteristic.

J. J. Torok (Corning Glass Works, Corning, N. Y.): This paper by Dawes and Reiter is quite interesting and timely. Some of the effects which they describe have previously been recognized and in some cases well understood. However, so sporadic was the work in this field that important secondary effects have been frequently overlooked.

The effects of the so-called island deposits can be often detected by radio interference measurements in the following manner:

The radio interference level of a clean insulator is first obtained. Then a voltage, slightly below flashover is applied for 5 minutes or more, after which the radio interference is again obtained. It will be found that the interference level after the application of voltage is somewhat higher than when the insulator was first tested. This rise in interference level is due to the deposit raising the surface conductivity around the pin and head of the insulator and reducing the gradient adjacent to the metal parts. The increase in surface conductivity seems to last for a considerable period of time.

Tests in which glass pin type insulators have been subjected to abnormally high voltages for periods of years show that the surface of the glass has not changed. This, of course, would be expected from the known chemical resistivity of glass. However, the tie wires and even the large conductor attached to the insulators were corroded. Apparently the acid depositing on the metal parts hastened the corrosion. This effect at first seemed quite rapid but after a period of several months when the protective coating was fully formed the rate of deterioration was considerably reduced. The lead head pins on which the insulators were mounted were likewise corroded. The conductors and pins on the no-static type of insulators that were included in these tests were practically free of corrosion, only the natural oxidation seemed to have taken place. The conducting layer in the pin hole and around the head eliminated the corona and prevented corroding acids from forming.

The study of electrical characteristics with varying loads, as the authors point out, shows only that relative movement between the hardware and porcelain or glass does take place.

One of the difficulties of measuring the loss in a sample dielectric is in obtaining an intimate bond between the electrodes and the dielectric. If the electrodes are not thoroughly bonded to the dielectric the resultant voids bring about losses and other inaccuracies of measurement. These factors in higher voltage measurements may even overshadow the losses in the dielectric. Therefore any slight movement of the cap or pin causing a change in the bond between the electrodes and the dielectric should be detected by power factor or capacitance measurements.

A study of the effects of mechanical loading on the electrical properties of glass has been made by Doctor Guyer and the results published in the *Journal* of the American Ceramic Society in 1933. In brief he found that mechanical stresses set up by shear, cantilever, or pure compression did not affect the electrical conductivity of glass. The variations in the properties of the insulator as shown in figure 13 are therefore undoubtedly caused by slight readjustment of the alloy both in the pin hole and in the cap.

Philip Sporn (American Gas and Electric Company, New York, N. Y.): The authors of this paper have done an excellent systematic and painstaking job in investigating the subject of insulator characteristics a hitherto altogether too neglected field. It is astonishing to find electrical characteristics of suspension insulators such as power factor, capacitance, watts loss, following a hitherto undiscovered trend detected here by the accurate measurements of small quantities under controlled laboratory conditions.

It is of course too soon to predict where this study of porcelain-insulator characteristics may lead us but the fact that the authors have developed and applied a technique for insulator testing ought, without doubt, to be of considerable benefit to the particular art and to the particular industry in general.

Specifically the application of this method of testing ought to be of great help in design testing of insulators, both present and new types, with a view of detecting those physical characteristics which are not obviously measurable but which do have an appreciable effect in determining insulator deterioration and insulator life. We, ourselves have carried out some work in this connection but the amount of further work to be done is astonishingly large and the handicap that we have been faced with heretofore owing to lack of proper instruments and technique ought to be at least partially removed by the application of some of the methods already disclosed by the authors and by a development and perfection of these methods. It is hoped that the authors themselves will continue their systematic research on insulator characteristics. I personally believe that the results so obtainable will be of considerable benefit to the electric power industry and to the electrical industry in general.

C. L. Dawes and **R. Reiter:** W. M. Goodhue states that it is remarkable that our power factor-absolute humidity characteristics are linear. We felt this same way when these characteristics were first obtained and in order to verify these relations we performed a considerable amount of experimental work over considerable periods of time and under wide ranges of atmospheric conditions. Moreover, data obtained by graduate students who conduct insulator tests as part of their laboratory work show this same linear relation, so that it seems to be an experimental fact. There has not, however, been opportunity to determine whether or not this relation is due to any fundamental law.

The material in this paper first appeared as part of a doctorate thesis, and specific humidity, rather than absolute humidity was used as the humidity parameter. The same linear relations of power-factor to humidity were obtained, however. The change to absolute humidity was made at the suggestion of the Institute Committee in order to conform to previous practice. Over the usual range of atmospheric conditions, the ratio of specific to absolute humidity is nearly constant, so that the character of the curves is not appreciably affected by the change. Goodhue states that evaporation from materials tends to increase with temperature just as water itself evaporates more at higher temperature, and the inference is that the insulator characteristics would seem to be functions of relative rather than absolute or specific humidity. This conclusion is logical and our initial reasoning was the same as his. Hence, as stated in the paper, every attempt was made to relate our chatacteristics to relative humidity, but we could find no definite relation. Fundamentally, with the insulator the phenomenon is one of adsorbed moisture. Surface adsorption of gases is often considered a physical effect and the gases adhere rather tenaciously to a surface. Possibly the relation of adsorbed moisture to temperature is quite different from that of water vapor intermingled with the atmosphere, which may be the explanation oft he fact that the characteristics are not directly related to relative humidity. There may be some temperature effect which is not yet known.

Goodhue feels that it would be important to know the effect of temperature on the sputtering action of corona on the metal wire and cap. This would, of course, be valuable as fundamental knowledge and might assist in the explanation of the humidity effects obtained. However, in our tests, although the temperature varied several degrees, the proportionate change in absolute humidity was very much greater than the proportionate change in temperature. Hence, the authors feel that the changes in humidity must have a much

greater effect on sputtering than does temperature.

The lag in corona measurements observed by Goodhue is undoubtedly due to the fact that corona formation is in part determined by the ionization conditions in the ambient air. It requires time for the number of free positive and negative ions in the ambient air to reach the steady-state value. The lag found by us is due primarily to the time required for the temperature of the surface to change and to the time required for the accumulation of surface deposit. In both cases lag is due to the fact that appreciable time is required for conditions to reach equilibrium. In his concluding comment, Goodhue summarizes quite completely the several factors contributing to the "hysteresis" effect.

In M. G. Malti's discussion, he has apparently confused the lag or hysteresis effect shown by us with the cyclic hysteresis occurring in magnetic and dielectric materials. Although both phenomena involve lag of the effect relative to the cause, the two are quite different phenomena. With magnetic and dielectric materials hysteresis involves molecular rearrangements and also storage of energy. The hysteresis observed by us is merely a lag of surface conditions with respect to the effects producing them, and no energy is stored at any part of the cycle. In fact, it is being dissipated continuously at each point on the hysteresis cycle. In the porcelain itself true dielectric hysteresis of course does occur, but this is a rapidly changing cyclic phenomenon, and except for the almost negligible energy loss, its effects do not appear in our steady-state measurements.

The circuit shown in figure 2*a* is not the usual Maxwell series-parallel combination of resistances and capacitances purporting to simulate the behavior of dielectrics when an electromotive force is impressed on them as stated by Malti. The circuit is an actual one consisting of true surface resistance in series combinations with the actual capacitances between the surfaces of the shell. Accordingly, the circuit is not a model and it can be replaced by the equivalent circuits of figures 2*b* and 2*c*, just as electrical networks can usually be replaced by more simple circuits.

The hysteresis effect shown in our capacitance characteristics as stated in the paper is due to the fact that changes in surface resistance vary the amount of effective shell capacitance in circuit between cap and pin. This does not involve the ratio of q to e in the same sense that it occurs during the cyclic changes in dielectrics.

In the last portion of his discussion, Malti enumerates the several factors which affect the results obtained by us and states that the work lacks fundamental importance. Most of the factors which he enumerates have been investigated in a fundamental manner and are represented by a large amount of published data, some of which are given in his bibliography. Yet so far as we know, up to now no one has been able to apply these data to a porcelain insulator to reach the conclusions given in the paper. It must be remembered that this is practically pioneer work in this particular field, and it is only due to these experiments with complete commercial insulators that we now know the several factors which affect the insulator characteristics. We have already been able to isolate some of the factors suggested by him and hope to publish these in a subsequent paper. We realize that these experiments have opened a wide field of research, as Malti's suggestions imply, and undoubtedly as time progresses, more will be known of the subject.

Sidney Withington refers to the effect of mechanical load on the electrical characteristics of the insulator. As he states, at certain loads there is a definite but small change in these characteristics. We agree with him that since these changes show some readjustment of pin and the cement they may be of some importance. In the time available we did not investigate this effect nearly as completely as we would have desired. He suggests that the effects of mechanical loading should be studied under recurring stress. We have done this to a limited extent, but the work should be carried much further to include several different designs of insulators and tests should be made under varying electrical stress and at different temperatures.

It is gratifying to learn from J. J. Torok that the results presented in the paper substantiate some of the effects noted in the past, such as radio interference. In fact, our discovery of the island deposits such as are shown in figure 8, and the statement that they cause radio interference, seem to be in accord with the measurements of radio interference, which he describes. His statement that the surface of glass does not change after being subjected to abnormally high voltages for periods of years we assume does not mean that the surface is immune from the surface deposits described in the paper. Although there was not opportunity to examine the surfaces of the glass insulator with the care devoted to the porcelain, the characteristic shown in figure 7 would indicate a pronounced surface deposit.

The information obtained by Doctor Guyer that the mechanical loading of glass does not affect its electrical characteristics shows that the changes in electrical characteristics shown in figure 13 must be due to readjustment of the alloy at the pin and cap.

It is also very gratifying to learn that Philip Sporn, who has had wide experience with insulators in service and under diverse operating conditions, feels that our work will be of considerable practical importance. We are continuing the work and hope that further developments in our technique will be of assistance in improving the design of insulators and in detecting faulty insulators.

Lightning Protection for Transmission Lines

Discussion of a paper by A. W. Gothberg and A. S. Brookes published in the January 1937 issue, pages 13–16, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 26, 1937.

L. V. Bewley (General Electric Company, Pittsfield, Mass.): The analysis given by the authors is based on a lightning stroke of constant magnitude (40,000 amperes) with a uniform rate of rise of 1,000 kv per microsecond. Figure 1 of this discussion shows the results of some calculations for the equivalent of 8 standard 10 x 5.75 suspension insulators based on assuming definite front lightning waves of 1-2-4 microseconds and the lightning expectancy curve given in "Flashovers on Transmission Lines," ELECTRICAL ENGINEERING, April 1936.

These curves take into account the tower-footing resistance, surge impedances of phase wires and lightning stroke (400 ohms), coupling factor, time lag of insulator flashover, and a "crest factor" depending upon the length of spans, lightning wave front, and successive reflections.

The left-hand curves give the percentage flashovers for a stroke to a protected pole, the middle column for strokes to an unprotected pole midway between protected poles, and the right-hand curves the consolidated results. The following conclusions may be drawn:

1. The longer the lightning wave front the fewer the flashovers, a 1-microsecond front causing

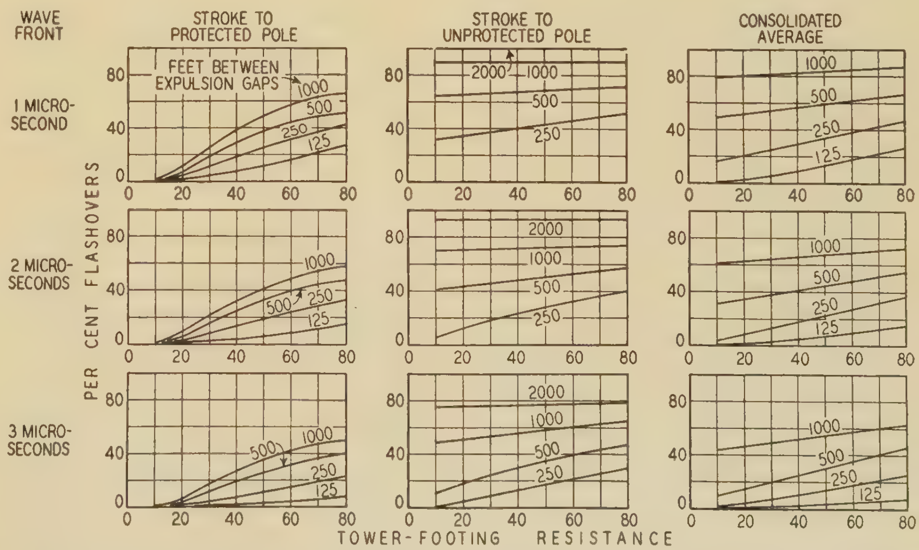


Fig. 1. Per cent flashovers for stroke to protected and unprotected poles with expulsion gaps on top phase only and with ideal shielding; 125-foot spans and 10- by 5.75-inch insulator units

perhaps twice as many flashovers as a 4-microsecond front.

2. The lower the tower-footing resistance the fewer the flashovers. But the curves are rather flat and the benefits of low footing resistance are by no means as good as in conventional ground wire practice. The reason is that resistance plays a minor rôle for a stroke at or near a pole not equipped with an expulsion gap, and as the number of unprotected poles between gaps increase, the bulk of flashovers become more independent of resistance. A stroke to an unprotected pole corresponds to a midspan stroke to a ground wire, with the essential difference that midspan flashover requires a very high voltage, whereas flashover of the insulation at the pole is comparatively small. The curves show that a reduction of resistance is about equally beneficial, regardless of wave front.

3. The percentage flashovers increase as the distances between gaps become greater, thus confirming the contention that the gaps should be installed at short intervals to realize their full advantages. Thus for a 2-microsecond wave front and footing resistances of 40 ohms the flashovers are:

Distance Between Gaps	125	250	500	1,000
Per Cent Flashovers	4	18	42	67

Lightning Investigation on a 220-Kv System—II

Discussion and author's closure of a paper by Edgar Bell published in the December 1936 issue, pages 1306–13, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 26, 1937.

L. V. Bewley: See discussion, page 626.

P. L. Bellaschi: See discussion, page 627.

S. K. Waldorf (Pennsylvania Water and Power Company, Baltimore, Md.): The surge current measurements on counterpoise conductors reported by Bell are of great value and more of them are needed, because they give an indication of the answer to one of the open questions in the design of lightning protection for transmission lines. This question is the proper length for counterpoise conductors. Bell has shown that currents flow along the counterpoise toward the point of stroke contact from as far away as $1^1/_2$ miles. This is a remarkable condition with tower footing resistances being as reported between 1 and 2 ohms. It would seem that such low footing resistances would permit neutralization of charge in the vicinity of a tower without charge flowing along the counterpoise for long distances. If such were the case, counterpoise conducors would not need to be so long.

The records presented in figure 2 of the paper must have been caused by a stroke having a relatively slow rate of voltage rise. Several microseconds must have been required for charge to travel more than a mile to the struck tower. The current law of Kirchhoff was followed at junctions of counterpoise and towers, a point not at first clear, as surges travel with different velocities on unburied and buried conductors. Maxima of surges on overhead ground wires and buried counterpoise under these conditions would not occur simultaneously at junctions, and the crest surge currents recorded would not obey Kirchhoff's current law. Apparently this effect did not enter into the measurements reported, indicating slow rates of current change.

The matter would be clarified to some extent if Bell would give details of the measurement of tower footing resistances on the line, such as amount of counterpoise and overhead ground wire included in the protective system during measurement and the reference used for the measurement. On this depends the conclusion which can be drawn whether the behavior noted is common to all types of counterpoise installation or only to counterpoises installed in soil of high resistivity.

Edgar Bell: Surge-crest ammeter records are not precision measurements and only tell the maximum or crest value of current without any indication of the time at which this maximum occurred, nor any direct indication of the current wave shape. Present technique allows any measurement to have an uncertain error; and the degree of accuracy of any single measurement is unknown. In general, however, surge-crest ammeter measurements appear to be consistent and reliable, but they have their limitations. Consequently, although the fact that the crest magnitudes of currents at various junction points in the overhead ground wire-tower structure-ground network apparently obey Kirchhoff's law, the accuracy of measurement does not permit us to say that reflections did not occur, but merely that such reflections were not particularly large.

Measurements of tower footing resistance were made during 1929 on the 14-tower section of line now equipped with continuous counterpoise. These were made under 4 conditions, namely:

1. Before installation of counterpoise, and with overhead ground wires disconnected from the tower under test.
2. Same as (1) but with overhead ground wires in place.
3. After installation of counterpoise and with overhead ground wires disconnected from the tower under test.
4. Same as (3) but with overhead ground wires in place.

Summarized results were as follows:

Method	Maximum Ohms	Minimum Ohms	Average Ohms
1	150	50	93
2	3.0	2.1	2.5
3	1.6	1.0	1.4
4	0.8	0.8	0.8

These resistance measurements were made with a megger ground tester. Measurements made in 1926 using a Kolrausch bridge and before overhead ground wires were installed gave approximately the same results as method 1.

The 1935 and 1936 counterpoise-current measurements show that currents flow for long distances, (except for extremely small lightning discharges) and indicate that lightning surges have relatively slow rates of voltage rise. The numerous records obtained some years ago from lightning stroke recorders also suggest that lightning strokes themselves do not have as rapid wave fronts as formerly assumed. Consequently the megger resistance measurements, except for the fact that they were made at low voltage and small current, more nearly approximate the resistances existing under lightning conditions than if lightning surges were of steep wave front.

First Report of Power System Stability

Discussion and closure of a report of the AIEE subcommittee on interconnection and stability factors published in the February 1937 issue, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 26, 1937.

A. C. Monteith (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The committee should be congratulated on the completeness of this first report on a very broad and involved system problem.

The vital facts are presented for a large number of systems already in operation. The introduction of the a-c calculating table has given a tool that simplifies the solution of involved systems being planned. Its use has allowed a very accurate treatment of the interconnection and stability problem

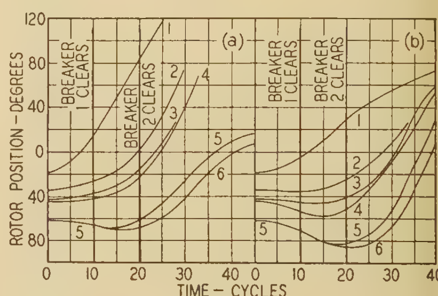


Fig. 1

(*a*)—Zero ohms tower-footing resistance
(*b*)—3 ohms tower-footing resistance

with considerable saving in time and also the elimination of the human factor from a large part of the solution. The attached figure not only illustrates the results obtained from the a-c calculating board on a particular 6-machine problem but further shows the effect of considering 3 ohms tower-footing resistance in the zero-sequence circuit for a fault just outside station 1. This is a very nominal amount of resistance and its consideration in this case saved going to higher speed breakers or the use of higher speed relaying.

In another study the system was stable when 5-cycle breakers and carrier-current relaying was used assuming no tower-footing resistance. The system was in a high-resistance area and no ground wires were contemplated. The consideration of 10 ohms tower-footing resistance allowed the use of standard 8-cycle breakers and impedance-type relays resulting in a large saving in the equipment. The value of resistance selected and when it can be used

will depend on the particular system under consideration.

The effect of tower-footing resistance is emphasized in this discussion to point out that the proper consideration of ground resistance sometimes permits the use of less expensive equipment. It is possible also that data of this character might have been collected from the operating companies and included in table III.

E. F. Scattergood (Bureau of Power and Light, City of Los Angeles, Calif.): This report has been of particular interest to me because the field covered and the results presented so closely parallel the similar work done with respect to the design of the Boulder Dam transmission system of the City of Los Angeles.

In connection with the study of system stability, a point that should receive special consideration in the future is the effect of the characteristics of system load. A considerable part of the load on a metropolitan system is not pure resistance or pure impedance but consists of induction motors. Under the lower voltages existing during the recovery period after the fault, such motors tend to draw increased currents, a condition unfavorable to system stability.

To account for this effect on our system in an approximate way that was reasonably easy to apply, the system load was assumed to be 40 per cent motor load; and the load conductance representing this portion of the total load was assumed to vary inversely as the square of the voltage at the load during the recovery period.

Power limits found by this method are about 15 per cent lower than if the usual assumption of fixed impedance load is made.

Also in connection with table III of the paper, I should like to made certain corrections with respect to item I, the Boulder Dam-Los Angeles line: Line *A*-4 should read 265,000 kw.

This corresponds to the minimum head rating of the 4 turbines. The value of 240,000 kv which you used is the operating capacity representing load delivered at the receiving end. This is taken as 0.8 of the theoretical stability limit determined as outlined in greater detail in my paper given in your bibliographical reference 158.

In line *C*-2, the short circuit ratio should have been given as 2.74 at 60 cycles.

In line *F*-5, in designating use of lightning arresters, it should have read: at terminal stations, yes; at switching stations, no.

C. W. Franklin (Consolidated Edison Company of New York, N. Y., Inc.): In discussing methods of increasing the stability of metropolitan power systems, the "Report of Power System Stability," includes the system arrangement known as "synchronized at the load." Since this arrangement was placed in operation in the New York area in 1929, it is felt that a review of operating experiences in this area and the modifications resulting from those experiences should be helpful to those contemplating such an arrangement.

In the original concept of a system of this type, each generator was connected to a group of feeders and thence to the load. The only paralleling connections between generators were to be at the load, which in the ultimate, would be the low-voltage network mains, and during the transition period would also be through the low-voltage busses at substations. Service continuity was assured by the segregation of sources and the connections to a given network were deversified between as many bus sections as were available in a generating station and where economically feasible, also by feeder connections to 2 stations. Circuit breaker duty was greatly reduced due to the high impedance of the connections between generators. Economical loading of generators was accomplished partly by rearrangement of station switching and in part by unbalancing feeder loads. Stability both steady state and transient was assured by calculation, test, and subsequent experience.

In attempting to operate generators and stations at their economic loadings, some unbalancing and thereby overloading of network transformers resulted, and difficulty was experienced due to premature operation of network protectors at light loads. Late in 1930, while transferring load from Hudson Avenue to Hell Gate, the substation connections opened and the accompanying unbalance on network transformers and mains in one of the districts resulted in some equipment damage.

As a result of these experiences, it was decided that there should be no load transfer through the high-impedance connections. Stations and sections within the stations were to be operated substantially in phase and economy transfer was obtained by switching within the stations and between stations, by direct tie feeders with load control devices.

The maximum size of network which could be re-energized after shutdown had long been a matter of concern and study and the system was therefore divided into a number of separate low voltage networks, several of which were supplied from 2 stations. The difficulty of co-ordination between different stations during system trouble led to the conclusion that quicker restoration would be effected after an interruption if each network is under the control of one operator and thereby supplied from one station.

As a result of these experiences we have adopted the following as our fundamental plan of system development. Generating stations will be interconnected by a system of direct tie feeders and the distribution load will be segregated into blocks which are small by comparison with the capacity of the interconnected stations.

1. The a-c network will continue to be divided into network areas, each area being completely segregated from all other network areas. The load in each area should be small enough, so that the area can be re-energized by the station which serves as its base supply. Stations will be properly subdivided to meet the following requirements.

2. Network feeders should carry load in only one network area and should not be bifurcated with feeders to other areas.

3. The supply to each network area should be distributed between 2 or more major bus sections and further distributed among 4 or more subsections, and network capacity provided so that each network area fed from the station may be carried in emergency with one major section out of service. If the station has 3 or more major sections, it should be possible to re-energize a dead network area with one major section out of service. Each major bus section or subsection should have complete automatic protection.

4. Each network area should be supplied from a single station except during periods of initial development when the station has insufficient facilities to meet the above requirements. When it is necessary to feed an area from 2 or more stations, the supply should be such that one of the stations can pick up and carry the area in emergency without the other stations. This requires that the base station should have connected to it at least $^2/_3$ of the feeder and distribution transformer capacity to the area.

5. Ties between stations should be adequate to pick up and carry the load of certain predetermined network areas fed from a station temporarily out of service due to mechanical trouble. These ties will generally be of capacity required for normal operating purposes such as economy of operation and pooling of reserve capacity.

A network system of this type has the following merits:

1. It is simpler to operate under normal conditions than any other type of system.

2. It requires a minimum of voltage and phase-angle control devices.

3. It minimizes the amount of operating co-ordination required for the restoration of service in the event of interruption and correspondingly simplifies the operating rules covering the re-energizing procedure.

4. In the event of the loss of communication or failure of the interconnections between stations, it enables each station to operate as an independent unit which in most cases will be able to supply all the load to the network areas which it serves.

5. It offers great flexibility in planning the expansion of the system.

To satisfy the above principles a station must be electrically segregated so as to substantially provide the equivalent of three or more stations at one location. This requires segregation of the switch and bus galleries by fire walls, so that fire will be confined to a small section of the station. In addition to automatic bus protection, any connections between major sections should be indirect physically and should have sufficient sets of automatic protection in the link to preclude the spread of electrical trouble. It is also desirable, if practical to sectionalize or make provision for quick sectionalization in case of failure on a steam or water main.

The work necessary at Hudson Avenue to satisfy these principles is practically complete and the new Waterside 60-cycle installation is being made in accordance with the fundamental plan. Plans for the revamping of Hell Gate are complete whereas plans for the rebuilding of the Sherman Creek galleries are being formulated. Further sectionalization of the network proceeds whenever the load in an area exceeds the permissible limit.

R. D. Evans: Franklin's discussion of the system arrangement known as "synchronised at the load" is of considerable interest. While the report referred to this method principally for the purpose of illustrating a principle applying to system arrangements, it is pertinent to include an authoritative statement covering the recent developments in connection with this scheme.

Monteith's discussion has emphasized the importance of the a-c calculating board in the solution of system stability problems. He has also called attention to the part which fault and tower-footing resistances plays in the stability studies. It may be pointed out that while fault resistance is usually a beneficial factor, it is possible for the fault path to be of very high resistance

and to accentuate the problem. It is suggested that in the preparation of future subcommittee reports consideration be given to the inclusion of data on faults and tower-footing resistance as part of the tabulations along the line suggested.

The method of representing the load at the receiving end of a transmission system has a considerable effect on the stability limits as pointed out by Scattergood. The particular method of approximation which he described is of considerable interest.

Scattergood's discussion has called attention to certain corrections to be made in table III of the report. In the same table on pages 278–9 Sels has called attention to the fact that the tabulation should show high tension bussing arrangements at both the sending and receiving ends of all eight lines listed under the Philadelphia Electric Company, Pennsylvania Power and Light Company, and Public Service Electric and Gas Company. If any other errors exist in the table it is quite desirable that attention should be called to them by subsequent written discussions.

Capacitor Motors With Windings Not in Quadrature

Discussion and authors' closure of a paper by A. F. Puchstein and T. C. Lloyd published in the November 1935 issue, pages 1235–9, and presented for oral discussion at the induction machinery session of the winter convention, New York, N. Y., January 27, 1936.

C. G. Veinott (Westinghouse Electric & Manufacturing Company, Springfield, Mass.): This paper is an interesting extension of Morrill's paper on the revolving field theory of the capacitor motor. In Morrill's paper, the 2 stator windings are assumed to be displaced by 90 electrical degrees in space; therefore, the voltage induced in one stator winding, by a revolving field set up by the other stator winding, is displaced 90 degrees in time from the voltage induced by its own rotating field. (This displacement may be either forward or backward, as the case may be.) This phase displacement of 90 degrees is taken care of in Morrill's paper by the use of the familiar j operator; it is $+j$ or $-j$; depending upon whether the displacement is forward or backward. The operator j always revolves a vector 90 degrees.

Puchstein and Lloyd use a more generalized operator, namely, a vector operator expressed in exponential form,

$$\epsilon^{j\alpha} \text{ or } \epsilon^{-j\alpha}$$

where α = any angle, expressed in radians.

This vector operator rotates a vector, either forward or backward by the angle α. The authors study the case of the capacitor motor where the windings are displaced by an angle, say α, and the more generalized operator just given is used to take care of the angular time phase displacement of α, occurring between the voltage induced in a winding by its own field and the voltage induced by the field of the other winding. The 2 generalized vector operators above, of course, have to be reduced to the slightly more familiar forms

$$\epsilon^{j\alpha} = \cos\alpha + j\sin\alpha$$

$$\epsilon^{-j\alpha} = \cos\alpha - j\sin\alpha$$

before they become usable in practical equations.

The new idea of this paper is the introduction of this general vector operator into Morrill's equations, which are then reworked, just as Morrill originally worked them; but with the different operator. This idea is the principal contribution of the paper. The authors are to be highly commended, however, for their working out quantitatively of a practical example showing the effect of using winding displaced by angle other than 90 degrees by comparing the performance with a conventional 90 degrees motor. Would that more AIEE authors followed this example!

The use of vector operators other than j is not new.

Fortescue uses a 120 degree operator or

$$\pm a = -\frac{1}{2} \pm j\frac{\sqrt{3}}{2}$$

in his classic paper on symmetrical co-ordinates.

Capacitor motors with windings not 90 degrees apart are of little commercial importance. The analysis of this paper is applicable to shaded-pole induction motors with distributed windings, a type which is of some commercial importance. The methods of this paper might also be used to analyze the performance of a 3-phase delta-connected induction motor with one open primary phase. This latter case could likewise be studied by Fortescue's methods.

A. F. Puchstein and **T. C. Lloyd:** We agree in general with the points expressed by Veinott.

He states, however, that $\epsilon^{\pm j\alpha}$ must be put into the form $\cos\alpha \pm j\sin\alpha$ before it becomes usable in practical equations. This of course (although a minor point) depends upon whether the calculation is carried on in rectangular or polar co-ordinates, since $\epsilon^{\pm j\alpha}$ is always equivalent to $1\angle\pm\alpha$.

Material for this paper aside from the reasons given therein, arose from the attempt to obtain torque equations which would be applicable to motors of various types in which the number of slots would not divide properly for 90 degrees displacement of windings. Replacement of the j operator by its more generalized form was not so obviously simple as it appears when dealing with such torque equations. The final value was obtained as the result of an integration covering 24 letter-size pages, although Lyon and Kingsley, by the aid of symmetrical co-ordinates, have given what appears to be a shorter process.

A portion of the business district of Milwaukee, Wis., scene of the Institute's forthcoming summer convention

Aero-Graphic Corp. Photo.

News

Of Institute and Related Activities

Institute's 1937 Summer Convention Offers Unusual Vacation Opportunities

THE Institute's annual summer convention, which will be held in Milwaukee, Wis., June 21–25, 1937, with headquarters in the Schroeder Hotel, offers many unique features. Milwaukee, situated on the shore of Lake Michigan, and the State of Wisconsin, with its numerous inland lakes, possess an unusual appeal for all lovers of sports and nature to combine business with vacation. The schedule of events includes the annual business meeting, 10 technical sessions, and 1 general session which is designed to interest a great many members and which is not concurrent with any of the other sessions. The afternoons will be devoted principally to committee meetings, conference sessions, sports, and inspection trips to plants of internationally known manufacturers. Evenings will be devoted to social functions and entertainment.

Vacation Opportunities

Members of the Institute are urged to consider the opportunities afforded for combining their vacations with the summer convention. Regardless of the kind of of vacation desired—whether it be the social gayety of a smart hotel, the peaceful comfort of a small resort, the rugged sport of a fishing lodge, the restful seclusion of a private cottage, or the good fellowship of tourist camps—all are available near Milwaukee. To the fisherman, Wisconsin offers 7,000 inland lakes and 10,000 miles of trout streams all well-stocked. To lovers of nature there is an abundance of wild life. The northern forests in many places are untouched by man; deer frequently are seen right from the highways. Wisconsin has 160,000 acres in 19 scenic state parks and forests at various points in the state, each possessing its own peculiar and impressive characteristics. To lovers of sports there is almost everything that could be sought, including bathing and swimming in inland lakes or Lake Michigan and Lake Superior, motor boating, sailing, canoeing, golfing and tennis. Members desiring additional information regarding Wisconsin as a vacation land may write to the chairman of publicity, summer convention committee: W. E. Gundlach, 231 West Michigan Street, Milwaukee, or to the Wisconsin Conservation Commission, State Capitol, Madison.

Friendliness and Hospitality Will Pervade the Inspection Trips

According to the committee, a feature of the inspection trips is that they will be not only interesting and valuable from a technical standpoint, but also outstanding in their personal or social aspects. A spirit of friendliness and hospitality will be exhibited along with production processes, new equipment, and new products: (See special message from summer convention committee elsewhere in this issue.) At least 3

Schedule of Events

Monday, June 21

9:00 a.m.—Registration

10:00 a.m.—Opening Session—Crystal Ball Room

Annual Business Meeting

Annual report of board of directors, in abstract, by H. H. Henline, national secretary

Report of committee of tellers on election of officers

Introduction of and response from president-elect

Presentation of prizes for papers

Presentation of Lamme Medal to Doctor Frank Conrad

President's address by A. M. MacCutcheon

12:45 p.m.—Inspection trip with luncheon at Harnischfeger Corporation, after which the group will divide for a lecture on prefabricated houses or inspection of the National Avenue plant

1:45 p.m.—Inspection trip to Cutler-Hammer, Inc.

2:00 p.m.—Conference of Officers, Delegates, and Members (*a*) Section delegates (*b*) Student Branch counselors

2:30 p.m.—Inspection trip to A. O. Smith Corporation

Evening —Stag Smoker

Tuesday, June 22

10:00 a.m.—Power Transmission

General Power Applications

Instruments and Measurements

Education

1:30 p.m.—Inspection trip to Schlitz Brewery—refreshments

2:00 p.m.—Conference of Officers, Delegates, and Members (continued)

Evening —Lecture by Doctor Vannevar Bush

Wednesday, June 23

10:00 a.m.—General Session

12:30 p.m.—Inspection trip to Allis-Chalmers Manufacturing Company—luncheon

2:30 p.m.—Conference on Electrical Apparatus for 3-Phase Arc Furnace

Evening —Boat trip on Lake Michigan—dancing, cards, and buffet service on steamer

Thursday, June 24

10:00 a.m.—Lightning Protective Equipment and Insulation Co-ordination

Power Generation and Electrical Machinery

Illumination

12:30 p.m.—Directors' luncheon meeting

Afternoon—Inspection trips to:

1. Port Washington Power Plant
2. A. O. Smith Corporation
3. Cutler-Hammer, Inc.

2:30 p.m.—Conference on Field Problems

Evening —President's Reception—dinner and dancing

Friday, June 25

10:00 a.m.—Lightning Protective Equipment and Insulation Co-ordination

Vibration and Balance

Communication and Research

Afternoon—Inspection trips to:

1. Globe-Union Manufacturing Company.
2. Allen-Bradley Company
3.* A. O. Smith Corporation (if shut down on previous days)

Evening —Farewell gathering at Blue Mound Country Club

Looking north along Lake Michigan and Lincoln Memorial Drive in Milwaukee

of the principal industries already have indicated a desire to provide luncheon for their visitors.

Trips already have been arranged to plants of the following companies: Allis-Chalmers Manufacturing Company, leading manufacturers of all types of heavy electrical equipment, including generators, motors, rectifiers, transformers, and switchgear, and also steam and hydraulic turbines, and tractors; A. O. Smith Corporation, makers of automobile frames, steel pipe, and pressure vessels; Cutler-Hammer, Inc., producers of electrical control and switching equipment; Harnischfeger Corporation, manufacturers of electric cranes and hoisting equipment, electric welders, and more recently a prefabricated steel home of new design; the Port Washington Power Plant of The Milwaukee Electric Railway and Light Company; and the Schlitz Brewing Company.

Milwaukee's Lake Shore and Harbor Facilities Add Interest

Attendants at the convention will have an opportunity to enjoy the natural scenery and recreational facilities along the beautiful shores of Lake Michigan. Lincoln Memorial Drive leads from downtown Milwaukee north along the lake shore for a distance of 5 miles to Lake Park. It affords a view of the harbor entrance, the Coast Guard station, Milwaukee Yacht Club, fine swimming beaches, Milwaukee Gun Club, and the beautiful treed ravines of Lake Park.

At the north end of the Drive is Milwaukee's new $5,000,000 water purification plant which is rapidly nearing completion. The plant is on 24 acres of made land on the shore of Lake Michigan. It will have a rated capacity of 200,000,000 gallons daily and uses what is known as the rapid sand or mechanical type of filtration. All pumping is by electric drive using a total of 4,000 installed horsepower.

Milwaukee has long been known as one of the important harbor cities of the Great Lakes, receiving and shipping a wide variety of commodities in both foreign and domestic commerce. It is a principal grain shipping port and the foremost coal receiving port on Lake Michigan. More than 4,000 vessels arrive at and clear this port annually. The tonnage in and out over a period of years averages in excess of 7,500,000 net tons annually.

Post-Convention Trip to the Dells

Many people attending the convention will not want to miss the opportunity of seeing the dells of the Wisconsin River. For this reason special arrangements are being made for a chartered-motor-bus trip to this and other scenic and historical spots on Saturday, June 26, the day following the close of the convention. The trip will include a visit to the dells in the morning, a chicken dinner at Kilbourn, a visit to Devil's Lake and the University of Wisconsin campus in the afternoon and evening dinner at the Hotel Lorraine at Madison, returning to Milwaukee after dinner. The expense of the trip will be very reasonable.

Future AIEE Meetings

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Aug. 30–Sept. 3, 1937

Middle Eastern District Meeting
Akron, Ohio, Oct. 13–15, 1937

Winter Convention
New York, N. Y., January 24–28, 1938

North Eastern District Meeting
Pittsfield, Mass., Spring 1938

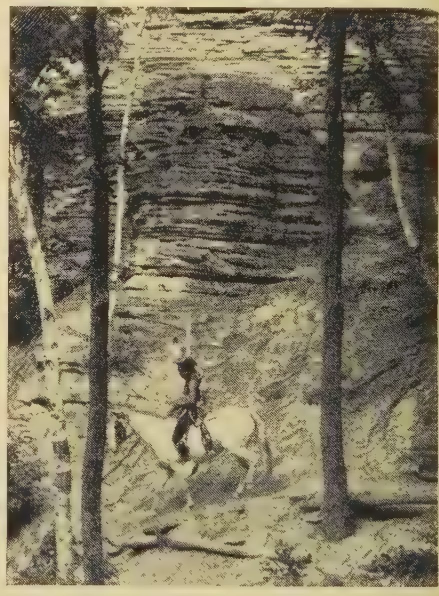
Technical Sessions

Ten technical sessions have been tentatively scheduled to provide a program of broad scope and current interest. Two sessions will be held on the subject of lightning protective equipment and insulation co-ordination. These sessions are sponsored jointly by the committees on protective devices, power transmission and distribution, and electrical machinery. The subject of insulation co-ordination was first introduced about 1928 and since has been discussed frequently by both operating companies and representatives of electrical manufacturers. Two of the papers report the latest information on the subject as developed by joint committees of the Edison Electric Institute and the National Electrical Manufacturers Association. Two others consist of reports by the lightning arrester subcommittee of the committee on protective devices and the transformer subcommittee of the committee on electrical machinery. The remaining papers are by operating-company engineers.

The subjects for other sessions are as follows: power transmission, general power applications (control), education, power generation and electrical machinery, illumination, vibration and balance, communication and research and instruments and measurements. Those interested in the technique of measurement should find the sessions on insulation co-ordination and vibration and balance also to be of interest. Several papers in the various sessions treat subjects of general interest, such as police radio, industrial economics and business methods, and industrial lighting.

General Session

Wednesday morning, June 23, has been set aside exclusively for a general session to be held in 2 parts. The first part will consist of an address by Ralph E. Flanders "The Engineer in a Changing World." The second part will consist of discussions by



A sample of the scenery in the "The Dells" of the Wisconsin River near Kilbourn. A special post-convention trip to this attraction is being arranged

various members of the Institute on the topic: "How Can the Institute Programs Be Made of Greatest Value to the Membership?" (See special announcement elsewhere in this issue.)

Rules on Presenting and Discussing Papers

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers

Tentative Technical Program

In this program, reference to the issue and, in so far as possible, to the page in ELECTRICAL ENGINEERING, is given for all papers.

Tuesday, June 22

10:00 a.m.—Power Transmission

POWER SYSTEM FAULTS TO GROUND—PART I: CHARACTERISTICS, C. L. Gilkeson, Edison Electric Institute, and P. A. Jeanne and J. C. Davenport, Bell Telephone Laboratories, Inc.
April issue, pages 421–8

POWER SYSTEM FAULTS TO GROUND—PART II: FAULT RESISTANCE, C. L. Gilkeson, Edison Electric Institute, and P. A. Jeanne and E. F. Vaage, Bell Telephone Laboratories, Inc.
April issue, pages 428–40

SYSTEM RECOVERY VOLTAGE DETERMINATION BY ANALYTICAL AND A-C. CALCULATING BOARD METHODS, R. D. Evans and A. C. Monteith, Westinghouse Electric & Manufacturing Company.
Scheduled for June issue

NEW OIL-FILLED CABLE LINES IN CHICAGO, Herman Halperin, Commonwealth Edison Company, and G. B. Shanklin, General Electric Company.
Scheduled for June issue

10:00 a.m.—General Power Applications

A-C MOTOR PROTECTION, C. W. Kuhn, Cutler-Hammer, Inc.
May issue, pages 589–93

IMPULSE OPERATION OF MAGNETIC CONTACTORS, Carroll Stansbury, Cutler-Hammer, Inc.
May issue, pages 583–8

COINCIDENTAL ELECTRIC DRIVES, L. E. Miller, Reliance Electric & Engineering Company.
May issue, pages 578–82

10:00 a.m.—Instruments and Measurements

A NEW MAGNETIC FLUX METER, G. S. Smith, University of Washington.
April issue, pages 441–5

SIXTY-CYCLE CALIBRATION OF THE 50-CENTIMETER UNGROUNDED SPHERE GAP, C. S. Sprague and G. Gold, Purdue University.
May issue, pages 594–6

A NEW PHOTOELECTRIC HYSTERESIGRAPH, R. F. Edgar, General Electric Company.
Scheduled for June issue

A NEW HIGH-SPEED CATHODE-RAY OSCILLOGRAPH, H. P. Kuehni and Simon Ramo, General Electric Company.
Scheduled for June issue

10:00 a.m.—Education

A SUGGESTED COURSE ON INDUSTRIAL ECONOMICS AND BUSINESS METHODS, R. E. Hellmund, Westinghouse Electric & Manufacturing Company.
April issue, pages 446–54

CURRENT LOCI IN THE GENERAL LINEAR A-C NETWORK, L. A. Hazeltine, Stevens Institute of Technology.
March issue, pages 325–30

PER UNIT QUANTITIES, Irven A. Travis, University of Pennsylvania.

FUNDAMENTAL CONCEPTS OF SYNCHRONOUS MACHINE REACTANCES, B. R. Prentice, General Electric Company.

Wednesday, June 23

10:00 a.m.—General Session

1. Address: THE ENGINEER IN A CHANGING WORLD, Ralph E. Flanders, chairman, engineering economics committee, American Engineering Council; President, Jones and Lamson Machine Company, and past-president, ASME.

Intermission

2. Discussion by members of the Institute on HOW CAN THE INSTITUTE PROGRAMS BE MADE OF GREATEST VALUE TO THE MEMBERSHIP?

2:30 p.m.—Conference on Electrical Apparatus for 3-Phase Arc Furnaces

Thursday, June 24

10:00 a.m.—Lightning Protective Equipment

FLASHOVER CHARACTERISTICS OF ROD GAPS AND INSULATORS, subcommittee on correlation of laboratory data of Joint NEMA-EEI Committee on Insulation Co-ordination.
Scheduled for June issue

EXPULSION PROTECTIVE GAPS, W. J. Rudge and E. J. Wade, General Electric Company.
May issue, pages 551–7

DISTRIBUTION LIGHTNING ARRESTER PERFORMANCE DATA, lightning arrester subcommittee of the committee on protective devices.
May issue, pages 576–7

SURGE PROTECTION OF DISTRIBUTION SYSTEMS, J. K. Hodnette and L. R. Ludwig, Westinghouse Electric & Manufacturing Company.

10:00 a.m.—Power Generation and Electrical Machinery

SWITCHBOARDS FOR BOULDER POWER PLANT, L. N. McClellan, U. S. Bureau of Reclamation, A. J. A. Peterson, Westinghouse Electric & Manufacturing Company, and C. P. Garman, Bureau of Power and Light, City of Los Angeles.
February issue, pages 224–36

END-CONNECTION REACTANCE OF ELECTRICAL MACHINERY, J. F. H. Douglas, Marquette University.
February issue, pages 257–9

END-WINDING LEAKAGE INDUCTANCE OF A SYNCHRONOUS MACHINE, B. H. Caldwell, Jr., General Electric Company.
April issue, pages 455–61

CHARACTERISTIC CONSTANTS OF SINGLE-PHASE INDUCTION MOTORS—PART I: AIR-GAP REACTANCES, W. J. Morrill, General Electric Company.
March issue, pages 333–8

Notice of Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Hotel Schroeder, Milwaukee, Wis., at 10 a.m. on Monday, June 21, 1937. This will constitute one session of the annual summer convention which is to be held this year in Milwaukee, Wis.

At this meeting, the annual report of the board of directors, and the reports of the committee of tellers on the ballots cast for the election of officers will be presented.

Such other business, if any, as properly may come before the annual business meeting may be considered.

(Signed) H. H. HENLINE
National Secretary

10:00 a.m.—Illumination

A NEW APPROACH TO THE INDUSTRIAL LIGHTING PROBLEM; SPECIFIC LIGHTING FOR DIFFERENT SERVICES, H. B. Dates, Case School of Applied Science.
May issue, pages 545–50

Address: WHAT A UNIVERSITY HAS DONE TOWARD PROTECTING THE EYESIGHT OF ITS STUDENTS, F. A. Kartak, Marquette University.

FURTHER CHARACTERISTICS OF THE CARBON ARC, W. C. Kalb, National Carbon Company, Inc.
March issue, pages 319–24

Demonstration Address: NEW LIGHT SOURCES, THEIR CHARACTERISTICS AND APPLICATIONS, D. W. Atwater, Westinghouse Lamp Company.

2:30 p.m.—Conference on Field Problems

Friday, June 25

10:00 a.m.—Insulation Co-ordination

BASIC IMPULSE INSULATION LEVELS, EEI-NEMA Joint Committee on System Insulation Co-ordination.
Scheduled for June issue

INSULATION STRENGTH OF TRANSFORMERS, transformer subcommittee of the committee on electrical machinery.
Scheduled for June issue

APPLICATION OF ARRESTERS AND THE SELECTION OF INSULATION LEVELS, J. H. Foote and J. R. North, The Commonwealth & Southern Corporation.
Scheduled for June issue

INSULATION CO-ORDINATION, Philip Sporn and I. W. Gross, American Gas & Electric Company.
Scheduled for June issue

APPLICATION OF SPILL GAPS AND SELECTION OF INSULATION LEVELS, H. L. Melvin and R. E. Pierce, Ebasco Services Incorporated.
Scheduled for June issue

10:00 a.m.—Vibration and Balance

DYNAMIC BALANCING OF SMALL GYROSCOPE ROTORS, O. E. Esval and C. A. Frische, Sperry Gyroscope Company, Inc.
Scheduled for June issue

VIBRATION MEASURING INSTRUMENTS: FUNDAMENTAL CONSIDERATIONS IN THEIR DESIGN, C. D. Greentree, General Electric Company.
Scheduled for June issue

THE VIBRATION ISOLATION OF MACHINERY, L. H. Hansel, The Felters Company, Inc.
Scheduled for June issue

PRELIMINARY REPORT ON A PROPOSED TEST CODE FOR APPARATUS NOISE MEASUREMENT, subcommittee on sound of standards committee.

10:00 a.m.—Communication and Research

POLICE RADIO COMMUNICATION, E. L. White, Federal Communications Commission, and E. C. Denstaedt, Police Department, Detroit.
May issue, pages 532–44

OXIDATION IN INSULATING OIL, J. B. Whitehead, The Johns Hopkins University, and F. E. Mauritz.
April issue, pages 465–74

PROPERTIES OF SATURANTS FOR PAPER-INSULATED CABLES, G. M. L. Sommerman, American Steel & Wire Company.
May issue, pages 566–76

THE DIELECTRIC STRENGTH OF NONINFLAMMABLE SYNTHETIC INSULATING LIQUIDS, F. M. Clark, General Electric Company.
Scheduled for June issue

will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted a somewhat longer time.

Hotel Schroeder, Milwaukee, headquarters for the summer convention

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th St., New York, N. Y., on or before July 9, 1937. Discussion received after this date will not be accepted.

Women's Entertainment

In addition to the regular entertainment the women's entertainment committee is arranging an attractive program for the visiting ladies, which will be announced later.

Sports

The annual tournaments for both the Mershon golf and tennis trophies will be held as usual, as well as the competition for the Lee golf trophy. The details of the sports program will be announced in a subsequent issue as soon as they have been made available by the sports committee.

Advance Registration

Members who will attend the convention are urged to register in advance by promptly returning the addressed advance-registration card which they will receive by mail. This will be helpful to the committees and permit badges to be made ready in advance, thus avoiding congestion at the registration desk.

A minimum registration fee of $2 will be charged all nonmembers, except Enrolled Students and the immediate families of members.

Hotel Reservations

All members planning to attend the convention should make their own hotel reservations, and the committee urges that this be done well in advance. A list of the principal hotels in Milwaukee and their rates for

Principal Hotels in Milwaukee, and Rates

Hotel	Single Room	Double Room
Schroeder	$3.00–4.00	$6.00–20.00
Wisconsin	3.00–5.00	5.00–10.00
Plankinton	2.50–4.50	4.00–15.00
New Pfister	2.50–3.00	4.00–15.00
Astor	3.50–5.00	4.00– 6.00
Ambassador	3.00–4.00	5.00– 6.00
New Randolph	2.50–3.50	3.50– 6.00
Knickerbocker	3.00	5.00– 6.00
Martin	2.25–5.00	
Juneau	2.00–3.00	3.00– 5.00
Medford	1.75–3.00	2.75– 5.00
Republican	1.50–2.50	2.50– 4.00
Miller	1.50–3.00	3.00– 5.00

To Summer Conventioners

GEMUTLICHKEIT is the only word to express adequately the spirit which will pervade the coming summer convention in Milwaukee. The entertainments, the hospitality extended to inspection-trip guests, and the sportsmanship displayed on links and courts, will all bear the stamp of *gemutlichkeit.*

One dictionary translation of this word is "quality of good nature," but experts in philology say that no English word, or combination of words, conveys its precise meaning. It is representative of a state of mind which must be lived and felt to be understood; that is, whatever it stands for must be "experienced" to be fully comprehended.

In Milwaukee a committee consisting of more than 60 able and alert men and women is so planning the convention that no one will leave without knowing the meaning of the word "gemutlichkeit." Never again will they have to look in the dictionary or inquire about this word whose meaning is so finely shaded and elusive that it can hardly be expressed with any degree of exactitude in any other language.

However, there are some ways in which you, our guests, can materially assist the committee to accomplish the task to which it has set itself, and I am sure we shall have your hearty cooperation.

(1) The committee will greatly appreciate it if you will make a serious effort to be present at the opening session of the convention. The tenor of a convention is often determined by the spirit which prevails at the first session. If this meeting is well attended and enthusiastically supported, the convention is sure to be a success. Furthermore, this session is the occasion of several impressive ceremonies, such as presentation of prizes and medals.

Above all, the members should keep in mind that the president delivers his annual message to the Institute at the opening session. Always of interest and importance to Institute members, the president's address has special significance when stirring times issue a challenge to professional organizations to take an active part in shaping the destinies of our civilization. No one attending the convention should miss the president's address.

(2) Some of the industries to which inspection trips will be made are planning to serve luncheons to their guests, and it will help them greatly to know as early as possible how many to prepare for. Therefore, register as early as you can for the inspection trips you intend to take.

(3) Elsewhere in this issue is published a list of the principal hotels in Milwaukee. All these hotels are within a 12- to 15-minute ride from convention headquarters (Schroeder). Because of these excellent facilities to please visitors with regard to housing, Milwaukee is a very popular convention city; and in order to avoid last minute congestion, choose your hotel and send in your reservation early. In case you have any difficulty, get in touch with the housing committee and efforts will be made to get you placed to your satisfaction. But do it early.

K. L. Hansen

General Chairman
Summer Convention Committee

single and double rooms are given in an accompanying tabulation. All are within a 12- to 15-minute ride from convention headquarters (Schroeder). Any one having difficulty in obtaining rooms should contact the housing committee.

COMMITTEE

The personnel of the 1937 summer convention committee is as follows: Otto H. Falk, *honorary chairman;* K. L. Hansen, *chairman;* L. H. Hill, *vice-chairman;* C. H. Krueger, *secretary;* W. E. Crawford, *treasurer;* R. R. Benedict, A. G. Dewars, C. F. Harding, H. S. Osborne, G. G. Post, J. A. Potts, D. L. Smith, and W. H. Timbie. Subcommittee chairmen: J. F. H. Douglas, technical program; E. W. Seeger, finance; L. W. Copeland, entertainment; C. D. Brown, transportation; W. O. Helwig, registration and housing; W. E. Gundlach, publicity; G. F. Crowell, sports; S. H. Mortensen, inspection trips; and Mrs. A. C. Flory, women's entertainment.

Session on Economics and Institute Activities

A special "general" session on the economic aspects of engineering and Institute activities has been scheduled for Wednesday morning, June 23, during the Institute's 1937 summer convention. The session, which will not be paralleled by any other, has been arranged by the newly appointed special committee on Institute activities, of which H. S. Osborne is chairman. The session will be divided into 2 parts, consisting of: (1) an address "The Engineer in a Changing World," by Doctor Ralph E. Flanders, president of the Jones and Lamson Machine Company, Springfield, Vt.; and (2) a discussion of the topic "How Can Institute Programs Be Made of Greatest Value to the Membership?" by various members of the Institute.

Doctor Flanders has devoted a large amount of time to engineering society activities, having served as president of the American Society of Mechanical Engineers and as member or chairman of many ASME committees. He is a vice-president of American Engineering Council and chairman of its committee on the relation of consumption, production, and distribution; since 1932 he has been active in the public works program of Council. During 1936 he was chairman of Council's committee on engineering economics, and has been a director of the Social Science Research Council. He has written numerous technical papers and 2 books.

Ralph E. Flanders

Doctor Flanders was born September 28, 1880, at Barnet, Vt., and started his technical career as an apprentice machinist in 1897. In 1903 he became a designer for the International Paper Box Machinery Company, Nashua, N. H., which position he held until 1905, when he became associate editor of *Machinery*, with offices at New York, N. Y. He held that position for 5 years before joining the engineering staff of the Fellows Gear Shaper Company. Springfield, Vt., in 1910. In 1912 Doctor Flanders became director and manager of the Jones and Lamson Machine Company, and has been president of that company since 1933. He has received several honorary degrees.

At the conclusion of Doctor Flanders' address, the meeting will be opened for any questions that those present may wish to ask concerning the subject. Then, after a brief intermission, the second part of the session will begin with brief discussions of various phases of Institute activities by several prominent Institute members, leading up to a general discussion from the floor.

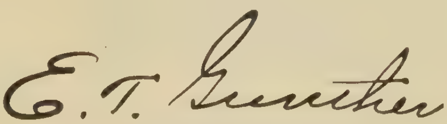
Membership—

Mr. Institute Member:

The Institute has done much to improve the status of electrical engineering as a profession but much remains to be done. Increased membership will materially aid achievement of one of the aims of the Institute—public recognition of our profession.

Too many of us regard our membership in the Institute as a matter of paying dues. We should attend meetings frequently and take an active part in the affairs of our local Section. We cannot arouse interest in nonmember electrical engineers unless we display interest ourselves.

Let's all take a nonmember guest to our next Section meeting and show him the advantages of membership in the Institute.



Vice-Chairman, District No. 7
National Membership Committee

AIEE Executive Committee Meets

A meeting of the executive committee of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on March 25, 1937, in place of the regular meeting of the board of directors.

Present: President A. M. MacCutcheon (chairman), F. M. Farmer, W. H. Harrison, Everett S. Lee, and W. I. Slichter, members of the committee; Vice-President A. C. Stevens, and National Secretary H. H. Henline. By standing vote, resolutions were adopted in memory of Junior Past-President E. B. Meyer, who died on January 30, and Past-President and Honorary Member Elihu Thomson, deceased, March 13. (The resolutions were published in the April issue of ELECTRICAL ENGINEERING.)

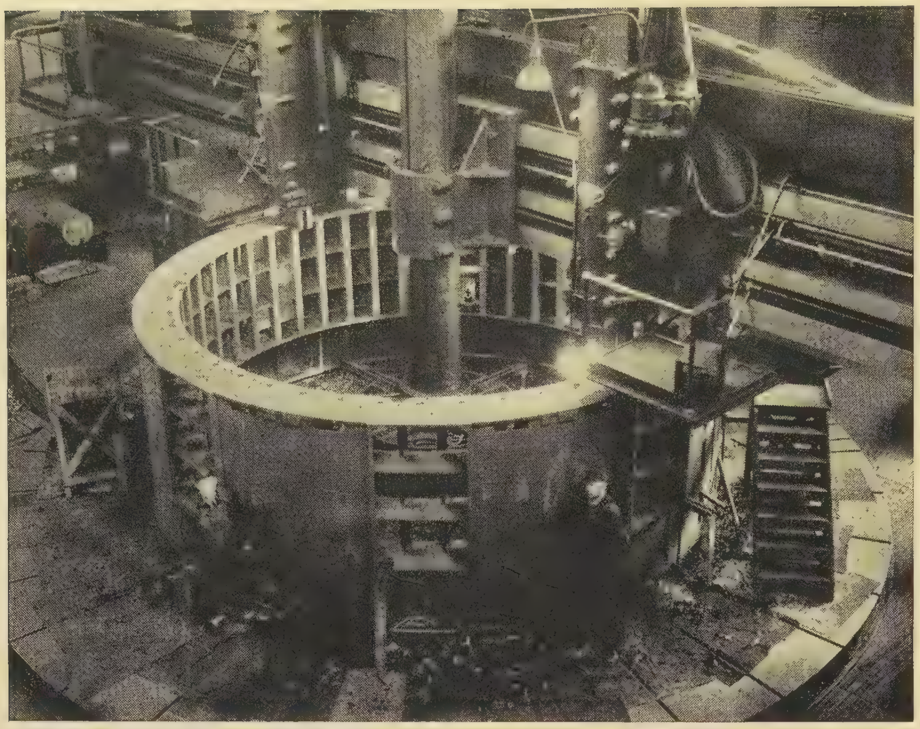
Reports were presented and approved of meetings of the board of examiners held February 17 and March 17, 1937. Upon the recommendation of the board of examiners, the following actions were taken: 1 applicant was elected to the grade of Fellow; 14 applicants were elected and 19 were transferred to the grade of Member; 96 applicants were elected to the grade of Associate; 106 Students were enrolled.

Monthly expenditures were reported by the finance committee and approved, as follows: February, \$27,819.71; March, \$17,691.20.

The selection by the District meeting committee of the dates, October 13–15, for the previously authorized 1937 meeting of the Middle Eastern District, at Akron, Ohio, was reported.

Doctor William McClellan was appointed a representative of the Institute upon the Hoover Medal board of award for the six-year term beginning in May 1937, succeeding Doctor F. B. Jewett, whose term expires at that time.

Professor R. W. Warner was appointed a third alternate of the Institute upon the delegatory committee for region V of the committee on engineering schools of the Engineers' Council for Professional De-



Machining a fabricated-steel stator yoke on a 40-foot boring mill in the plant of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis. An inspection trip to this plant during the forthcoming AIEE summer convention has been scheduled

velopment, in connection with the accrediting of engineering schools by ECPD.

The executive committee confirmed the appointment, upon nomination by the standards committee, of Doctor Clayton H. Sharp to represent the Institute upon the subcommittee of the United States National Committee of the International Commission on Illumination to consider a proposal of the National Bureau of Standards for the international standardization of photometric units.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

President MacCutcheon Visits New England Sections

During the week of March 8, 1937, President A. M. MacCutcheon, accompanied by National Secretary H. H. Henline, Vice-President A. C. Stevens, and R. G. Lorraine, secretary of the North Eastern District, visited 5 Sections and one Student Branch of the Institute. This brief report of the tour has been prepared from information supplied by District Secretary Lorraine.

The following meetings were attended by the group:

New Haven, Conn. Dinner followed by meeting of Connecticut Section.

Lynn, Mass. Meeting of national members of Lynn Section and dinner as guests of the General Electric Company, followed by general Section meeting.

Boston, Mass. Dinner followed by Section meeting.

Providence, R. I. Luncheon with Providence Section and Brown University Branch followed by joint meeting of Brown University and Rhode Island State College Branches.

Worcester, Mass. Dinner followed by joint meeting of Worcester Section and Worcester Polytechnic Institute Branch.

Springfield, Mass. Dinner followed by Section meeting.

President MacCutcheon spoke on "The Selection and Training of Electrical Engineers" at the New Haven, Boston, Providence, and Springfield meetings; and on "The Section's Part in Institute Activities" at the Worcester meeting. The dinners preceding the meetings were featured by intimate and informal discussions of Institute policies and procedures. At some of the meetings, in addition to the talks by the president, Vice-President Stevens made short talks on District activities; National Secretary Henline discussed the Sections' records as the national organization sees them, and District Secretary Lorraine discussed the forthcoming District meeting.

At the Worcester Section meeting; left to right: District Secretary Lorraine, Professor T. H. Morgan (A'23, M'31) of Worcester Polytechnic Institute, President MacCutcheon, Admiral Ralph Earle, National Secretary Henline, and Vice-President Stevens

In addition to the meetings, the group visited the Cambridge (Mass.) plant of the Simplex Wire and Cable Company, where they were conducted on the inspection trip by officials and other members of the organization; this was followed by a luncheon in the private dining room of the company. At Springfield, Mass., an inspection was made of the Westinghouse plant under the direction of Section Chairman C. G. Veinott and others, and of the United American Bosch plant by officials of that company.

Baltimore Section Is Host to Student Branch Convention

In 1925, the Philadelphia Section initiated the idea of AIEE Student Branch conventions. Since that time, other Sections in the eastern portion of the Middle Eastern District have joined with the Philadelphia Section in promoting and supporting this successful phase of Institute activities. During the ensuing 12 years, the idea has been widely and effectively adopted by other Sections and Districts.

Monday, April 19, 1937, was Student Branch convention day at The Johns Hopkins University school of engineering, Baltimore, where the thirteenth such meeting of the eastern section of District No. 2 was held, with about 190 students, faculty members, and others interested in attendance. The day's program was full, with a technical session in the morning, a noon luncheon, an afternoon inspection trip, and an evening dinner meeting.

At the technical session, 4 student technical papers were presented:

A LABORATORY POLYPHASE POWER RECTIFIER, T. Chase, Drexel Institute, Philadelphia, Pa.

ELECTRICAL TIME STANDARDS, T. R. Brown, Lehigh University, Bethlehem, Pa.

AN ALGEBRAIC EQUATION SOLVER, D. L. Herr and R. H. Graham, University of Pennsylvania, Philadelphia, Pa.

APPLICATIONS OF A SONIC OSCILLATOR, L. Broomell, Swarthmore College, Swarthmore, Pa.

By decision of a committee of judges, Mr. Brown was awarded a first prize of $10 and Mr. Chase a second prize of $5. Presiding throughout the session was Chairman H. B. Peck of the Johns Hopkins student Branch. Preliminary introductory remarks were made by AIEE Past-President J. B. Whitehead, dean of the school of engineering of Johns Hopkins University, by AIEE President A. M. MacCutcheon, who discussed Institute activities, services, and affairs, by R. L. Thomas, chairman, Baltimore Section, and by National Secretary H. H. Henline.

Those attending the sessions were the guests of the Johns Hopkins Student Branch at luncheon where Dr. Isiah Bowman, president of The Johns Hopkins University, addressed the group on "Flood Control." An afternoon inspection trip to the plant of the Locke Insulator Corporation gave to those attending an opportunity to witness a demonstration of high-voltage insulator testing, and also to observe the

A group of those that attended the recent Southern District Student Branch conference at Alabama Polytechnic Institute

manufacture of porcelain insulators by the wet process.

The evening dinner meeting was held jointly by the Johns Hopkins Student Branch and the Baltimore Section in honor of President MacCutcheon, who spoke on "The Selection and Training of Electrical Engineering." Past-President Whitehead and President-Designate Harrison, and others spoke briefly.

With the co-operation of the Baltimore Section, the meeting was jointly participated in by the 8 Student Branches of the eastern section of the Middle Eastern District:

Drexel Institute, Philadelphia, Pa.
The Johns Hopkins University, Baltimore, Md.
Lafayette College, Easton, Pa.
Lehigh University, Bethlehem, Pa.
University of Pennsylvania, Philadelphia, Pa.
Princeton University, Princeton, N. J.
Swarthmore College, Swarthmore, Pa.
Villanova College, Villanova, Pa.

Although having no Student Branches, the University of Delaware and Haverford College both contributed support. Visiting Branches also participating in the meeting were:

Catholic University of America, Washington, D. C.
George Washington University, Washington, D. C.
University of Maryland, College Park, Md.

A generous delegation of students and faculty was present representing each of the Branches.

Plans already decided upon provide for similar meetings at Lehigh University in 1938, and at Drexel Institute in 1939.

1937 AIEE Year Book Is Now Available

In accordance with the provisions of the Institute's 1936–37 budget as approved by the finance committee and the board of directors, the 1937 edition of the AIEE Year Book has been issued, in limited edition, and is available to members of the Institute who have use for it. The book contains essentially the same material as was included in the 1936 edition; business and mailing addresses have been corrected as of February 27, 1937.

In keeping with established custom, copies of the Year Book have been distributed to all national, District, and Section officers, to Student Branch counselors, and to all members of all national committees. Other members wishing to secure a copy may do so by writing to the AIEE order department, 33 West 39th Street, New York, N. Y., giving correct mailing addresses.

The Year Book is not available to nonmembers of the Institute, nor is its use permitted for commercial, promotional, or other circularization purposes.

Student Conference Held at Alabama Polytechnic

Some 140 of the South's top-ranking students in electrical engineering, and Student Branch counselors from 15 colleges and universities registered at the annual student conference of the AIEE Southern District, held April 1–3 at Alabama Polytechnic Institute, Auburn. All principal features of the program were confined to Friday, April 2, with Thursday afternoon given over to registration followed by an informal smoker in the evening, and Saturday devoted to inspection trips to Tuskegee Institute and to hydroelectric plants of the Alabama Power Company on the Coosa River.

For the first time since the initiation of the Student Branch conferences in the Southern District, every Branch in the District was represented:

Alabama Polytechnic Institute, Auburn, Ala.
University of Alabama, University, Ala.
Clemson Agricultural College, Clemson, S. C.
Duke University, Durham, N. C.
University of Florida, Gainesville, Fla.
Georgia School of Technology, Atlanta, Ga.
University of Kentucky, Lexington, Ky.
Louisiana State University, Baton Rouge, La.
University of Louisville, Louisville, Ky.
Mississippi State College, State College, Miss.
North Carolina State College, Raleigh, N. C.
University of North Carolina, Chapel Hill, N. C.
University of South Carolina, Columbia, S. C.
University of Tennessee, Knoxville, Tenn.
Tulane University, New Orleans, La.
Virginia Military Institute, Lexington, Va.
Virginia Polytechnic Institute, Blacksburg, Va.
University of Virginia, University, Va.

Six technical papers were presented at the Friday morning technical session:

Elimination of Man-Made Static, Gordon Rogers, Clemson College, Clemson College, S. C.

A Treatise on Rural Electrification, J. E. Lowery, Alabama Polytechnic Institute, Auburn, Ala.

Testing Vacuum Tubes, T. M. Ferril, Jr., Mississippi State College, State College, Miss.

High Frequency Radio Transmitters, Wayne Mason, University of Florida, Gainesville, Fla.

An Electrical Nurse, J. A. Potter, Georgia School of Technology, Atlanta, Ga.

Notes on a Series Scheme of Modulation, C. W. Harrison, Jr., University of Virginia, University Va. (Presented by Mr. Porter of University of Virginia.)

At the elaborate banquet held Friday evening, a first prize for the best technical paper was presented to Mr. Mason, with second and third honors conferred, respectively, upon Mr. Potter and Mr. Rogers. The presentation of prizes was made by Professor W. W. Hill, counselor of the Student Branch at Alabama Polytechnic Institute and chairman of the District committee on student activities. Professor Hill carried the principal responsibilities of the conference, ably assisted by L. C. Balch, chairman of the API Student Branch.

Principal speaker at the banquet was National Secretary H. H. Henline. The gist of his address was to the effect that engineering, instead of having in the near future a decadent place in modern civilization, will have an increasingly important place and opportunity to function in the world's development. He stressed the need for engineers of the future to have a greater knowledge of economics and a better understanding of social problems. Mark Eldredge, AIEE vice-president for the Southern District, also spoke briefly as did some others including API President L. N.

The student authors of papers presented at the Southern District Student Branch conference

(Left to right) James A. Potter (2d prize) Georgia Tech; T. M. Ferrill, Jr., Mississippi State; G. J. Porter, Virginia; Gordon Rogers (3d prize) Clemson; John E. Lowery, Alabama Poly.; Wayne Mason (1st prize) Florida

Duncan. The toastmaster was Professor John C. McKinnon of the API mechanical engineering faculty. Following the banquet an engineers' ball was held for visitors and API engineering students at the college's newly constructed WPA Hall.

At a short official business session Friday afternoon, Virginia Military Institute was selected as the location for the next annual District Student Branch conference. Colonel S. W. Anderson, professor of electrical engineering at VMI and counselor of its Student Branch, accordingly was elected chairman of the District committee on student activities and designated so to represent the Fourth District at the forthcoming summer convention. An extended discussion among counselors and students led to a decision to restrict to 20 minutes the time allowed for the presentation of technical papers, but to allow unlimited time for discussion of them. The papers committee decided to give preference to papers based upon original investigations.

Chicago Section Sponsors Joint Meeting on Economics

At a joint meeting on March 22, 1937, the Chicago Section of the AIEE and the Western Society of Engineers heard 2 papers on "A Broader Field of Action for the Engineers." In the first, P. B. Juhnke (M'20, F'36) discussed the position of the engineers in the general economic structure of the nation and urged that they become better acquainted with questions involving the production and consumption of goods and the effect of changes in the monetary system. The second paper, presented by F. R. Innes (A'25, M'26) western editor of *Electrical World*, discussed the part that the engineer can take in directing the activities of the government in the electric-power field.

Some 200 members and guests of the participating bodies attended the meeting. According to Earle Wild (A'27, M'36) chairman of the publicity committee of the Chicago Section, those present expressed themselves as being highly in favor of meetings of this type. Further, it was the reported consensus of opinion that engineering societies in general should take more effective action concerning public affairs and broad economic problems within their respective fields.

ASTM Standards Index. An index to the standards and tentative standards of the American Society for Testing Materials which gives information as of January 1, 1937, has been made available. Copies are furnished without charge on request to ASTM headquarters, 260 South Broad St., Philadelphia, Pa.

Willard Gibbs Medal Awarded. Doctor Herbert Newby McCoy, internationally known for his achievements in radioactivity and in many other fields of chemical science, has been awarded the 1937 Willard Gibbs Medal of the Chicago (Ill.) section of the American Chemical Society. Doctor McCoy, for 16 years a member of the faculty of the University of Chicago and now vice-president and director of research of the Lindsay Light and Chemical Company, Chicago, was cited as "pioneer in a greater number of fundamental discoveries than any but 3 or 4 living American chemists." The medal was founded in 1911, and is awarded by a national jury of scientists.

High-Voltage Conference to Be Held in Paris

The ninth session of the International Conference on High Voltage Electric Systems (CIGRE) is scheduled to be held in Paris, France, from June 24 to July 2, 1937. This permanent organization of CIGRE was created in 1921 under the auspices of the International Electrotechnical Commission, and its biennial sessions bring together delegations from 40 different countries for the discussion of all problems relating to the design, construction, and operation of high-voltage electric systems. The last session in 1935 was attended by more than 1,200 delegates including government officials, power-utility engineers and executives, electrical manufacturers, and university professors interested in high-voltage developments.

At the June session in Paris, 112 technical papers from 20 different countries are already scheduled to be presented, including the following 6 American papers:

1. High-Speed Clearing and Ultra-High-Speed Reclosing of Faulted High-Voltage Transmission Lines, by Philip Sporn (A'20, F'30) American Gas and Electric Company, New York, N. Y., and D. C. Prince (A'16, F'26) General Electric Company, Philadelphia, Pa.

2. Lightning Currents on Transmission Lines, by W. W. Lewis (A'09, M'13) General Electric Company, Schenectady, N. Y.

3. Lightning-Stroke Tests on High-Voltage Apparatus in the Laboratory, by P. L. Bellaschi (A'29, M'34) Westinghouse Electric and Manufacturing Company, Sharon, Pa.

4. Lightning-Proof Transmission Lines, by A. F. Bang (A'11) and Edwin Hansson (A'19, M'35) both of the Pennsylvania Water and Power Company, Baltimore, Md.

5. Investigation by Precise Measurements of Suspension-Insulator Design Characteristics From the Standpoint of Service Requirements, by L. A. Meisse and J. J. Taylor, both of the Ohio Brass Company, Barberton.

6. Insulating Oils, by K. S. Wyatt (A'32) The Detroit (Mich.) Edison Company.

The proceedings are conducted in English, French, and German, and advance copies of all papers are available to all registered delegates. All delegates and their families are accorded reductions of 50 per cent in railway fares, and 40 per cent in hotel rates in France, and visits have been arranged for the delegates to the Paris International Exposition and to interesting electrical installations as well as to points of historical and scenic interest.

A permanent United States national committee has been formed, composed of Frederic Attwood (M'27), F. A. Allner (A'12 M'14), P. L. Bellaschi (A'29, M'34), W. W. Lewis (A'09, M'13), E. L. Moreland (A'11, F'21), Philip Sporn (A'20, F'30), and a large American delegation is expected to attend the June session in Paris. Further information may be obtained from CIGRE Headquarters, 54 Avenue Marceau, Paris, or from the president of the United States national committee, Frederic Attwood, 50 Church Street, New York, N. Y.

Perkin Medal for 1937 Presented. Thomas Midgley, Jr., vice-president of the Ethyl Gasoline Corporation, was presented with the Perkin Medal for 1937 of the Society of Chemical Industry at a joint meeting of the society and the American Chemical Society held on January 8, 1937. The medal is awarded annually for the most valuable work in applied chemistry and was presented to Mr. Midgley in recognition of his work in the development of antiknock motor fuels and safe refrigerants. Mr. Midgley is a fellow of the American Association for the Advancement of Science, and a member of the American Chemical Society, American Institute of Chemical Engineers, Society of Automotive Engineers, and other organizations.

Joint Summer Session on Economics Planned

The seventh annual economics conference for engineers will be held at Stevens Institute of Technology camp, Johnsonburg, N. J., June 18–26, 1937, concurrently with a summer session sponsored by the Society for the Promotion of Engineering Education on the study of economics in engineering colleges. Members of the conference will be welcome at any of the lectures arranged for the SPEE session. A series of evening lectures by leading authorities on economic and industrial topics has been arranged for both groups. The 4 courses planned are:

1. Industrial Management, conducted by Professor George W. Barnwell of Stevens Institute of Technology.

2. Course Content and Teaching Methods organized by Professor W. D. Ennis of Stevens Institute of Technology and conducted by several lecturers.

3. Industrial Economics, conducted by Doctor Dexter S. Kimball, formerly dean of engineering, Cornell University, and Professor W. D. Ennis of Stevens Institute of Technology.

4. Industrial Psychology, conducted by Doctor R. W. Uhrbrock, head of research department, industrial relations division, The Procter & Gamble Company.

Correspondence on enrollment should be addressed to President Harvey N. Davis, Stevens Institute of Technology, Hoboken, N. J.

Semiannual Meeting of ASME. The American Society of Mechanical Engineers will hold its semiannual meeting at Detroit, Mich., May 17–21, 1937. The meeting will stress the contribution of the automotive industry to industry in general, al-

though power plant engineering and other subjects will be included. The use of the Diesel engine will be discussed in several railroad sessions. Inspection trips to points of interest in the vicinity of Detroit have been arranged and include the River Rouge plant of the Ford Motor Company, Connors Creek station of The Detroit Edison Company, and the continuous strip mill of the Great Lakes Steel Corporation.

Triennial Montefiore Prize Award Now Open

Constituting interest on 150,000 Belgian francs, distributed triennially in international competition for the best original work presented on scientific advancement and progress in technical application of electricity in every field, the George Montefiore Foundation prize award now is open again to candidates. The amount available for 1938 is 18,000 francs (about $600); the closing date for entries is April 30, 1938.

The competition is limited to works presented during the 3 years that immediately precede the meeting of the jury of award. Papers either signed or anonymous are acceptable in typewritten manuscript or printed form, and must be written in either French or English and submitted in duplicate. By a $^4/_5$ vote of the jury of award, composed of 5 Belgian and 5 other electrical engineers, $^1/_3$ of the available amount may be awarded to a person who has not taken part in the competition, or to a work which without completely fitting the program, discloses a new idea that may have important developments in the electrical field.

The secretary-registrar of the foundation may be addressed at the headquarters of the Association des Ingénieurs Électriciens, 31 Rue Saint-Gilles, Liege, Belgium.

TVA Report. The annual report of the Tennessee Valley Authority for the fiscal year ended June 30, 1936, has been printed as a 377-page paper-bound volume, and may be obtained from the Superintendent of Documents, Washington, D. C., at 55 cents per copy.

Niagara Hudson Companies Consolidate

The Buffalo General Electric Company, the Niagara Electric Service Corporation, and the Tonawanda Power Company have filed a certificate of consolidation with the department of state at Albany, N. Y., following receipt of an order of the public service commission approving the consolidation of these companies as the Buffalo Niagara Electric Corporation. The announcement by Colonel William Kelly, (F'25) president of the Buffalo Niagara & Eastern Power Corporation, parent company for the 3 operating units involved in the consolidation, points out that the move is a further step in the simplification of the corporate structure of the Niagara Hudson power system, and reduces the number of system companies to 33 from a total of 59 in existence on December 31, 1929, the year the Niagara Hudson Power Corporation was formed.

The Buffalo General Electric Company was incorporated in 1892 from a consolidation of 2 smaller companies, and in 1915 absorbed a third company. Under another name, Niagara Electric Service Corporation also was formed in 1892, and adopted its present name in 1915; in 1928 2 smaller companies were acquired. The Tonawanda Power Company was incorporated in 1899 as a consolidation of 2 companies. Together these companies serve over 700,000 people.

Pennsylvania Railroad Continues Electrification

The Pennsylvania Railroad has awarded contracts to 5 companies for continuation of electrification work. The chief lines now to be electrified are the main line from Paoli, near Philadelphia, to Harrisburg, Pa.; the freight line from Morrisville, Pa., near Trenton, N. J., to Harrisburg; the freight line from Columbia, Pa., to Perryville, Md.; and the freight line from Monmouth Junction to South Amboy, N. J. This will mark the completion of the original electrification program on the eastern lines as announced by the railroad in 1928. The work will be financed by a $52,670,700 bond issue, and is expected to be completed in 18 months.

The new work will involve electrification of 315 miles of line and 773 miles of track. Upon completion of the work, the Pennsylvania Railroad system will have 2,677 miles of electrified trackage. The new construction work will be of the same type as that now employed elsewhere in the railroad's eastern electrified territory. It is known as the cross-catenary construction, based on a system of overhead conductors held in place by an arrangement of flexible wires supported between structural steel poles set in concrete beds beyond the outer edges of the track.

The 4-track main line of the Pennsylvania is now electrified between New York, Trenton, Philadelphia, Wilmington, Baltimore, and Washington, as are also the commutation lines around Philadelphia and New York.

Annual Convention of American Transit Association. The 56th annual convention of the American Transit Association and its affiliates will be held September 19–23, 1937, at White Sulphur Springs, W. Va. The convention is expected to bring together executives, operators, and mechanical men representing more than 90 per cent of the transit operations in the United States, Canada, and Mexico. Representatives of manufacturing companies also will attend.

Personal Items

W. D. Coolidge (A'10, M'34, Edison Medalist '27) director of the research laboratories of the General Electric Company, Schenectady, N. Y., recently was awarded a John Scott Medal "for the application of a new principle in X-ray tubes," as announced in the April 1937 issue of Electrical Engineering, pages 495-6. Doctor Coolidge was born October 23, 1873, at Hudson, Mass., and received the degrees of bachelor of science in electrical engineering (1896) and doctor of philosophy (1899) at Massachusetts Institute of Technology and the University of Leipzig (Germany), respectively. Following his graduation in 1899 he was appointed to the faculty of Massachusetts Institute of Technology in 1901, as an instructor in physical chemistry. In 1904 he was promoted to assistant professor of physicochemical research, but served in that capacity for only one year before joining the staff of the General Electric research laboratories at Schenectady. From 1908 until 1927 Doctor Coolidge served as assistant director of the research laboratories, and in 1928 was made associate director. He has been director of the laboratories since 1932. He has been active in many branches of electrical research, but is most widely known for his development of a process for manufacturing ductile tungsten for use in incandescent lamps, for the Coolidge X-ray tube, for improvements in submarine detecting devices, and

W. D. COOLIDGE

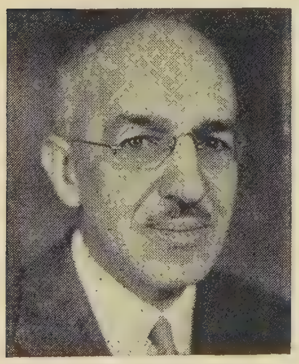
for researches on cathode-ray tubes. Doctor Coolidge received the Edison Medal in 1927 "for his contributions to the incandescent electric lighting and the X-ray arts." He has been honored by several

other scientific organizations, having received the Rumford Medal in 1914 "for invention and applications of ductile tungsten," the Howard N. Potts Medal "for development of a new and improved X-ray tube," the Louis Edward Levy Medal of the Franklin Institute, the gold medal of the American College of Radiology, a medal of award at the Panama-Pacific International Exposition in 1915, the Hughes Medal of the Royal Society in 1927, and the Washington Award in 1932. Doctor Coolidge served the Institute as a member of the committee on electrophysics from 1927 to 1929. He has contributed the results of his original researches to many scientific publications, and has presented several papers before the Institute. Doctor Coolidge is a member and past-vice-president of the Washington Academy of Sciences, and honorary member of the American Roentgen Ray Society, a fellow of the American Academy of Arts and Sciences, and a member of the American Chemical Society, American Electrochemical Society, American Physical Society, National Academy of Sciences, American Association for the Advancement of Science, Radiological Society of North America, American College of Radiology, and several foreign scientific societies. He was a member of the Corporation of Massachusetts Institute of Technology from 1930 to 1935.

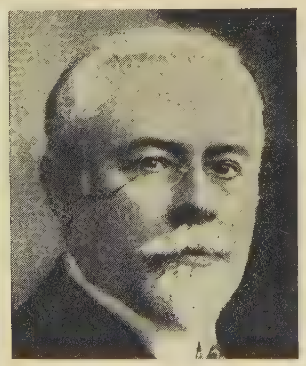
R. H. Tapscott (A'18, F'29, past vice-president) who has been vice-president in charge of electrical operations, Consolidated Edison Company of New York (N. Y.), Inc., recently was elected president and a trustee of that company. Mr. Tapscott was born in Brooklyn, N. Y., August 31, 1885 and was graduated from Union College with the degree of bachelor of science in electrical engineering in 1909, following which he joined the testing department of the General Electric Company, Schenectady, N. Y. Shortly afterward he was transferred to the lighting engineering department, where his work largely involved co-operation with a group of New York utility companies. In 1917 Mr. Tapscott left the General Electric Company to become assistant chief electrical engineer of the New York Edison Company. In 1925 he was promoted to the position of electrical engineer, and in 1932 became vice-president of that company and of the United Electric Light and Power Company. In 1936 he was elected vice-president of the Consolidated Edison Company of New York when the New York Edison Company, Inc., was merged with the Consolidated Edison Company. For the last 5 years Mr. Tapscott has been co-ordinating the engineering, construction, and operation of the electric companies affiliated with the Consolidated Edison Company. He served the Institute as a director (1930-34) and as a vice-president (1934-36); in addition, he has been a member of the committees on standards, 1924-29; electrical machinery, 1926-27; power transmission and distribution, 1926-28; headquarters, 1928-36 (chairman, 1929-33); Edison Medal, 1930-34; finance, 1931-36 (chairman, 1934-36); and co-ordination of Institute activities, 1934-36. Mr. Tapscott was active in the former National Electric Light Association. He was chairman of the electrical apparatus committee, and later a member of the engineering national committee of that organization.

André Blondel (A'05, HM'12) professor of applied electricity at l'Ecole Nationale des Ponts et Chaussees, Paris, France, has been awarded the Faraday Medal of the British Institution of Electrical Engineers. The medal is awarded once each year for notable scientific or industrial advancement in electrical engineering, or for conspicuous service rendered to the advancement of electrical science. Professor Blondel was born at Chaumont, France, in 1863, and was graduated from the universities of Paris and Dijon in 1889. He was then appointed engineer in the Department des Ponts et Chaussees (civil engineering), and from 1890 to 1927 was engaged in the lighthouse service of that department, with the titles of engineer-in-chief and inspector-general. He has held his present position as professor of applied electricity since 1904. During his long service, Professor Blondel has been instrumental in introducing many important changes in signaling on the coasts of France, principally by means of radio. In 1897 he conducted an exhaustive series of experiments on the electric arc, which led him to study the measurement of electrical quantities and to develop the art of photometry, a field in which he has long been a leading authority. His investigations have been extended to include the advancement of electrical theory and practice in relation to many types of equipment. He is perhaps most famous for his 2-reaction theory of synchronous machines and his work on the oscillograph, although he has to his credit many inventions in widely diversified electrical applications. His published contributions to electrical-engineering literature have been extensive. He has presided over committees and commissions, national and international, and has received many honors in his own land and abroad.

R. A. Millikan (M'22, HM'33, Edison Medalist '22) director of the Norman Bridge Laboratory of Physics and chairman of the executive council of California Institute of Technology, Pasadena, has been awarded a 1937 Franklin Medal of the Franklin Institute "for his isolation and measurement of the fundamental unit of electricity, the electron." Doctor Millikan was born at Morrison, Ill., March 22, 1868, and received the degree of bachelor of arts at Oberlin College in 1891; in 1895 he received the degree of doctor of philosophy at Columbia University, and during the following year attended the universities of Berlin and Göttingen. He has received honorary degrees from universities in the United States and other countries. From 1891 to 1893 Doctor Millikan tutored in physics at Oberlin College, and in 1896 became an assistant in physics at the University of Chicago, becoming assistant professor in 1902. In 1906 he became associate professor and continued to serve in that capacity until he was appointed professor in 1910. Since 1921 he has been director of the Norman Bridge Laboratory of Physics and chairman of the executive council of California Institute of Technology. Doctor Millikan has conducted many fundamental experiments in physics that have become important contributions to scientific knowledge. Recently he has been active in researches pertaining to the so-called cosmic ray and to the physics of the electron, although many of his earlier investigations were more directly applicable to electrical engineering. Doctor Millikan is a member of many technical and scientific societies in the United States and in foreign countries, and has served as president of several of them.



R. H. TAPSCOTT



ANDRÉ BLONDELL

R. A. MILLIKAN

H. A. Winne (A'16) manager of sales in the mining and steel mill section of the industrial department, General Electric Company, Schenectady, N. Y., has joined the engineering department of that company as general assistant to the vice-president in charge of engineering. Mr. Winne, a native (1888) of Cherry Valley, N. Y., attended Syracuse University, graduating in 1910 with the degree of electrical engineer. In the same year he entered the employ of the General Electric Company as a student engineer in the testing department. In 1911 he became head of the large motor, generator, and synchronous converter test, and in the following year was made assistant general night foreman of the testing department. In 1916 Mr. Winne was promoted to the power and mining engineering department, where he remained until 1922, when he was transferred to the steel

mill section of the industrial engineering department. He became head of the steel mill section in 1930, and in 1936 was appointed manager of sales of the combined mining and steel mill sections. Mr. Winne is a member of the Institute's committees on electric welding and applications to iron and steel production.

E. V. Caton (M'23) chief engineer and manager of power production, Winnipeg (Man., Canada) Electric Company, has been elected president of the Association of Professional Engineers of Manitoba. Mr. Caton, a native (1884) of Hore, England, attended Brighton Technical College and Sheffield University, and received an honors certificate from the City of Guilds Institute in Electrical Engineers. He received his early technical training in various English firms before going to Canada in 1912 to accept a position as chief engineer of the Hydro Electric System of the City of Winnipeg, with full charge of extensions and construction. In 1922 he became electrical engineer for the Winnipeg Electric Company and has been manager of that company since 1925.

C. H. Sharp (A'02, F'12, member for life) consulting engineer, White Plains, N. Y., has been appointed to represent the Institute upon the subcommittee of the United States National Committee of the International Commission on Illumination to consider a proposal of the National Bureau of Standards for the international standardization of photometric units. Doctor Sharp is a member of the Institute's committee on standards and of the Thomas Alva Edison Foundation.

W. S. Gordon, Jr. (A'27, M'35) has resigned as superintendent of electrical construction at the Philadelphia, (Pa.) Navy Yard to accept a position as supervising engineer with Vare Brothers, Philadelphia, in connection with that firm's portion of the Harrisburg electrification of the Pennsylvania Railroad. Mr. Gordon is co-author of a paper "A Review of European Railway Electrification," published in the April 1932 issue of Electrical Engineering, pages 244-52.

William McClellan (A'04, F'12, past-president) president of the Potomac Electric Power Company and the Washington (D. C.) Railway and Electric Company, has been appointed a representative of the Institute upon the Hoover Medal board of award for the 6-year term beginning in May 1937. Doctor McClellan is also the Institute's representative on the council of the American Engineering Council.

A. A. Thompson (A'08) Downers Grove, Ill., an employee of the General Electric Company, has received a 1936 Charles A. Coffin Foundation award "in recognition of his unusual keenness in seeing trouble and his persistence in correcting it." Mr. Thompson has been associated with the General Electric Company since 1905.

R. W. Warner (M'28) professor of electrical engineering, University of Kansas, Lawrence, has been appointed a third alternate upon the delegatory committee for region 5 of the committee on engineering schools of the Engineers' Council for Professional Development, relative to the accrediting of engineering schools by the Council.

T. O. Sweatt (A'33) recently resigned from the electrical department of Gibbs & Cox, Inc., marine architects and engineers, New York, N. Y., to accept a position with the consulting engineering firm of Gibbs & Hill, Inc., New York.

E. C. Brown (A'26) assistant manager, Connecticut Valley Power Exchange, Hartford, Conn., recently was elected chairman of the New England System Operators' Club.

H. A. Wagner (A'98, M'03) president of the Consolidated Gas, Electric Light, and Power Company of Baltimore, Md., has been elected a member of the executive committee of the Baltimore Association of Commerce.

H. C. Hamilton (A'23, M'26) superintendent of the standardizing and testing department of the Edison Electric Illuminating Company of Boston, Mass., has been elected chairman of the New England Electrical Equipment Committee.

Obituary

Edgar Knowlton (A'11) electrical engineer, General Electric Company, Schenectady, N. Y., died January 19, 1937. Mr. Knowlton was born July 7, 1871, at Portland, Me., and received his formal engineering education through correspondence schools and independent study. He entered the employ of the General Electric Company in 1893 as a draftsman on a-c motor and generator design, and was continuously associated with that company for almost 44 years. In 1899 Mr. Knowlton was transferred to the a-c engineering department on preliminary mechanical and electrical design of a-c machinery, and in 1903 was transferred to the design of turboalternators. Later he was placed in charge of turbogenerator design, and for many years was engaged in a-c engineering problems.

James Dhu Andrew (A'06) manager of The American Boiler Manufacturers Association, New York, N. Y., died March 22, 1937. Mr. Andrew was born October 29, 1874, at Brooklyn, N. Y., attended the school of mines of Columbia University and in 1899 became a mechanical engineer for the Metropolitan Street Railway Company of New York, N. Y. From 1903 to 1906 Mr. Andrew was chief engineer for the New York Edison Company. For 6 years thereafter he was superintendent of power for the Boston (Mass.) Elevated Railway Company, following which he was superintendent of engineering for the Edison Electric Illuminating Company of Boston. Later he was manager of ship construction of the Hog Island Shipyard, president of the American Balsa and Balsa Refrigerator Company, New York, and president of the Standard Tank Car Company, Sharon, Pa. He served also as vice-president of Stevens and Wood, Inc., of New York, in charge of design, construction, and operation of some power plants in Ohio. From 1926 to 1929 Mr. Andrew was a general consulting engineer for Armour & Company, Chicago, Ill. Later he was chief engineer of the Niagara Hudson Power Corporation. He was a member of The American Society of Mechanical Engineers and the Society of Naval Architects and Marine Engineers.

Frederick Stewart Cutting (M'31) deputy public service engineer of the City of Providence, R. I., died March 13, 1937. Mr. Cutting was born January 18, 1882, at Cranston, R. I. In 1904 he became assistant to the president of the Massie Wireless Telegraph Company, Providence, and was placed in charge of design, construction, testing, and maintenance. He remained in the employ of that company until 1912, when he was engaged as an electrician for the New London (Conn.) Ship and Engine Company. In the following year he became chief clerk of the power and line department of The Rhode Island Company, which later became the United Electric Railways Company. During the World War, and until 1923, Mr. Cutting served in the United States Navy, first as an instructor in electrical engineering at the United States Naval Radio School at Harvard University, and later as an engineering officer and inspector of machinery. From 1923 to 1926 he was employed in electrical construction work for the Dwight P. Robinson Company and the Carleton-Mace Company, of Boston, Mass., and for a brief period was employed as appraisal engineer for Jackson and Moreland, consulting engineers. In 1927 Mr. Cutting was appointed deputy smoke inspector for the City of Providence; in 1929, deputy public service engineer. He was a member of The American Society of Mechanical Engineers.

Frank George McRae (A'07) New York Power and Light Corporation, Albany, N. Y., died January 24, 1937. Mr. McRae was born February 5, 1879, at Schuylerville, N. Y., and was graduated from Cornell University with a degree in electrical engineering in 1902. In 1903 he entered the employ of the Hudson River Electric Power Corporation, Albany, where he served in various capacities in the operating department of that company until 1914. At that time he became superintendent of distribution of the Adirondack Electric Power Corporation at Glen Falls, N. Y. In 1922 Mr. McRae was transferred to the Amsterdam (N. Y.) offices of that company and in the following year to the Schenectady offices. He remained in the Schenectady offices of the Adirondack Electric Power Corporation until 1928, when he became associated with the New York Power and Light Corporation at Albany.

Membership

Recommended for Transfer

The board of examiners, at its meeting on April 14, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Childerhose, E. A., senior engineer, Federal Power Commission, New York, N. Y.
Donnell, P. S., dean of division of engineering, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
Eshbach, O. W., special assistant, personnel department, American Telephone and Telegraph Company, New York, N. Y.
Newton, J. M., president, The Roland T. Oakes Company, Holyoke, Mass.
4 to Grade of Fellow

To Grade of Member

Baines, H. A., technical assistant to executive staff, The Narragansett Electric Company, Providence, R. I.
Barron, D. W., vice-president and assistant engineer, Albert F. Ganz, Inc., New York, N. Y.
Clary, H. L., erecting engineer, Allis-Chalmers Manufacturing Company, Boulder City, Nev.
Connell, D. J., electrical engineer, The Scranton Electric Company, Scranton, Pa.
Crumley, H. L., electrical engineer, E. M. Gilbert Engineering Corporation, Reading, Pa.
Defandorf, F. M., physicist, National Bureau of Standards, Washington, D. C.
Linney, R. W., transmission and protection engineer, Southwestern Bell Telephone Company, Oklahoma City, Okla.
Long, Marvin, engineering assistant to toll fundamental plan engineer, Bell Telephone Company of Pennsylvania, Philadelphia.
Peterson, J. B., aeronautical engineer, National Bureau of Standards, Washington, D. C.
Schuetz, R. F., audio facilities engineer, National Broadcasting Company, Inc., New York, N. Y.
Wichum, Victor, chief engineer, C. J. Tagliabue Manufacturing Company, Brooklyn, N. Y.
Wilfley, V. B., electrical engineer, Westinghouse Electric & Manufacturing Company, Portland, Ore.
12 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade folllows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before May 31, 1937 or July 31, 1937, if the applicant resides outside of the United States or Canada.

Allen, S. R., Washington Water Power Company, Spokane, Wash.
Anderson, J. R., New York Worlds Fair, Inc., New York, N. Y.
Atkinson, J. M., California Institute of Technology, Los Angeles, Calif.
Banks, G. F., Commonwealth Edison Company, Chicago, Ill.
Bauerle, J. L., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Baur, H. W., Eastman Kodak Co., Rochester, N. Y.
Bender, D. S., 1835 Arch Street, Philadelphia, Pa.
Bingham, H. C., Cleveland Electric Illuminating Company, Cleveland, Ohio.
Bittrick, W. E., Consolidated Gas, Electric Light, and Power Company, Baltimore, Md.
Brand, S. (Member) Bell Telephone Laboratories, Inc., New York, N. Y.
Brewster, L. C., Ohio Bell Telephone Company, Cleveland, Ohio.
Butler, C. H., Portland General Electric Company, West Linn, Ore.
Carey, A. J., New York Telephone Company, Brooklyn, N. Y.
Carr, B. P., The Commonwealth & Southern Corporation, Jackson, Mich.
Chase, C. N., New York Rapid Transit Corp., Brooklyn, N. Y.
Chase, G. E., Public Utilities Commission, Bowmanville, Ont., Canada
Colby, P. S., Kansas Gas and Electric Company, Wichita, Kans.
Crevi, I. P. (Member) Westinghouse Electric & Manufacturing Company, New York, N. Y.
Cupitt, I. M. (Member) American Telephone and Telegraph Company, New York, N. Y.
Dailey, J. A., General Electric Company, Kansas City, Mo.
Devereaux, A. J., Central Nebraska Public Power and Irrigation District Hastings, Nebr.
Dietsch, R. C., Texaco Development Corporation, Los Angeles, Calif.
Edwards, J. H. (Member) General Cable Corporation, New York, N. Y.
Enquist, E. A. Jr., Consolidated Edison Company of New York, Inc., New York, N. Y.
Fletcher, G. R. (Member), Virginia Public Service Co., Alexandria, Va.
Galle, Paul F., Tennessee Valley Authority, Knoxville, Tenn.
Garrett, P. A. (Member) Commonwealth Edison Company, Chicago, Ill.
Gaskill, H. R., 4415 Pine Street, Philadelphia, Pa.
Gatchell, O. W. (Member) Cooper Wire Engineering Association, Washington, D. C.
Gibson, G. P., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Hartzell, H. W., Locke Insulator Corporation, Baltimore, Md.
Henderson, O., Ohio Bell Telephone Company, Cleveland, Ohio.
Henderson, W. D., 3721 Locust Street, Philadelphia, Pa.
Hendricks, J. B., The Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Herter, C. C., New York and Queens Electric Light and Power Company, Flushing, N. Y.
Holme, S. A. (Member) General Electric Company, Schenectady, N. Y.
Hughes, P. E., Star Route, Newburgh, N. Y.
Jirka, F. J., Public Service Company of Northern Illinois, Chicago, Ill.
Jones, J. O., Pacific Gas and Electric Company, Oakland, Calif.
Jordan, T., American Smelting and Refining Company, Garfield, Utah.
Julian, L. P., Duke Power Company, Charlotte, N. C.
Kelley, R. R., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Kethley, B. L., South East Joslyn Company, Atlanta, Ga.
Kocsis, P., R. K. O., Franklin Theatre, New York, N. Y.
Koester, H. F. (Member) New York and Queens Electric Light and Power Company, Flushing, N. Y.
Kostriza, J. A., 90 St. Mark's Place, St. George, Staten Island, N. Y.
Lack, F. R. (Member) Bell Telephone Laboratories, Inc., New York, N. Y.
Latta, E., Airway Electric Appliance Corp., Toledo, Ohio.
Lukacs, J. J., Bell Telephone Laboratories, Inc., New York, N. Y.
MacDonald, L. L., Public Service Electric and Gas Company, Newark, N. J.
Mancini, P. S., 65 Chatham Street, Providence, R. I.
Markuson, O. S., Bell Telephone Laboratories, Inc., Baltimore, Md.
Marshall, A. E. (Member) Monsanto Chemical Company, St. Louis, Mo.
Marshall, M. B. Jr., Jackson and Moreland, Boston, Mass.
Matthysse, I. F., Burndy Engineering Company, New York, N. Y.
Maull, J. R., Massachusetts Institute of Technology, Cambridge, Mass.
Mayberry, W. R., H. J. Heinz Company, Pittsburgh, Pa.
McCarthy, E. J., Bell Telephone Laboratories, Inc., New York, N. Y.
McElroy, C. H., Department of Water and Power, Los Angeles, Calif.
McIntosh, F. H. (Member) Pacific Coast Radio Engineer, for Graybar Company, San Francisco, Calif.
McNeice, L. G. (Member), Orillia Water, Light, and Power Commission, Orillia, Ont., Canada.
McWilliams, H. G., Southern California Telephone Company, Los Angeles, Calif.
Mead, S. P. (Mrs.) Bell Telephone Laboratories, Inc., New York, N. Y.
Mintz, L. L., Parker-Kalon Corporation, New York, N. Y.
Morgan, G. W., E. I. Du Pont Company, Richmond, Va.
Moseley, F. N., Southwestern Bell Telephone Company, St. Louis, Mo.
Murdock, H. E., Montana Power Company, Bozeman, Mont.
Murray, T. F., United Light and Power Engineering and Construction Company, Davenport, Iowa.
Nebe, H. G., WSMB Radio Station, New Orleans, La.
Nelson, A. E., Jr., Arkansas Power and Light Company, Pine Bluff, Ark.
Nelson, R. D., Line Material Company, South Milwaukee, Wis.
Newton, E. G. (Member) General Electric Company, Pittsfield, Mass.
Nicholson, H. H., Electric Storage Battery Company, Cleveland, Ohio.
Nofrey, C. E., 3014 Clay St., San Francisco, Calif.
Norman, G. H. L., Aerovox Corporation, Brooklyn, N. Y.
Page, F. M., The Reliance Electric & Engineering Company, Cleveland, Ohio.
Paige, H. W. (Member) Peters and Peters, Inc., New York, N. Y.
Patterson, H. M., 825 Union Trust Building, Washington, D. C.
Peck, R. R., Kansas City Power and Light Company, Kansas City, Mo.
Rahe, E. P., Western Electric Company, Baltimore, Md.
Rohr, E. K., Iowa State College, Ames.
Rohwer, O. J., Sargent and Lundy, Inc., Chicago, Ill.
Roush, C. G., Westinghouse Electric & Manufacturing Co., Kansas City, Mo.
Safranek, R. C., Washington Water Power Company, Spokane, Wash.
Schatz, G. W., Pennsylvania Power & Light Company, Allentown, Pa.
Scott, J. A., United States Treasury Department, Washington, D. C.
Seels, H. F., R.C.A. Manufacturing Corporation, Harrison, N. J.
Sickel, E. C., Northern States Power Company, West St. Paul, Minn.
Small, A. R. (Member) Underwriters' Laboratories Inc., Chicago, Ill.
Smith, L., Appalachian Electric Power Company, Charleston, W. Va.
Softli, R. R. B., 247 West 63d Street, New York, N. Y.
Spears, V. W., Public Service Company of Indiana, Bedford, Ind.
Stein, A. D. Jr., General Cable Corporation, New York, N. Y.
Stickel, O., A. I. Smith Corporation, Milwaukee, Wis.
Sullivan, D. E. (Member) Westinghouse Electric and Manufacturing Company, New York, N. Y.
Sullivan, J. W., S. S. White Dental Manfacturing Company, Princess Bay, S. I., N. Y.
Summers, S. D., Tri-State College, Angola, Ind.
Targonski, E., Arrow Hart and Hegeman Electric Company, Hartford, Conn.
Taylor, R. W., Tennessee Valley Authority, Knoxville, Tenn.
Thomas, P. E. (Member) Rochester Gas and Electric Corporation, Canandaigua, N. Y.
Thompson, W. B., E. M. Gilbert Engineering Corporation, Reading, Pa.
Tilson, H. MacM. (Member) San Francisco–Oakland Bay Bridge, San Francisco, Calif.
Tindall, H. D., Wagner Electric Corporation, St. Louis, Mo.
Todd, A. W., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Tollefson, M. W., Century Electric Company, St. Louis, Mo.
Traves, J. R., Bell Telephone Company of Canada, Toronto, Ont., Canada.
Vitale, R. L., Department of Water Supply, Gas and Electricity, Richmond, N. Y.
Wallace, T. M., General Electric Company, Erie, Pa.
Warfield, W. (Member), Tampa Electric Company, Tampa, Fla.
Westerkamp, P. R., Consolidated Edison Company of New York Inc., New York, N. Y.
White, P., Phoenix Engineering Corporation, New York, N. Y.
Widess, M. B., Western Geophysical Company, Los Angeles, Calif.

112 Domestic

Foreign

Accioly, P. B., Rio de Janeiro Tramway Light and Power Company, Brazil, S. A.
Barney, G. C. (Member), American Telegraph and Telephone Company and Bell Telephone Laboratories Inc., London, England.
Johnson, F. J. (Member) Honolulu Rapid Transit Company, Ltd., Honolulu, Hawaii.
Lazarus, V. E., "Sunnyside" Waltair, South India.

4 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Evans, Maldwyn F., Canadian Comstock Company, Ltd., Star Building, Toronto, Ont., Canada.
Hale, Edward E., Public Service Commission of New York, 80 Centre St., New York, N. Y.
Little, Leroy C., 3414—17th St., N., Cherrydale, Va.
Nash, G. H., 2-A Holland Road, London W.14, England.
Schaefer, Philip E., 5154 St. Paul Avenue, Chicago, Ill.
Wickel, F. A., Pier 42, Dollar S. S. Lines, San Francisco, Calif.

6 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

VDE-FACHBERICHTE, volume 8, 1936. Berlin-Charlottenburg, Verband Deutscher Elektrotechniker. Illustrated, 12x8 in., paper, 10.20 rm.; bound, 13.50 rm. Contains papers delivered at the 1936 meeting of the Verband Deutscher Elektrotechniker. Discusses many branches of electrical engineering: power generation, distribution, communications, lighting, and high-frequency engineering.

SYMPOSIUM on RADIOGRAPHY and X-RAY DIFFRACTION METHODS, held at the 39th Annual Meeting of the American Society for Testing Materials, Atlantic City, N. J., June 30–July 1, 1936. Philadelphia, American Society for Testing Materials, 1937. 350 pages, illustrated, 9x6 in., cloth, $4.00. A collection of papers on the uses of X rays and gamma rays for testing materials. Provides an account of the available methods and suggests future developments.

PROTECTION of ELECTRIC PLANT. By P. F. Stritzl. London and New York, Pitman Publishing Corporation, 1936. 200 pages, illustrated, 9x6 in., cloth, $6.00. Provides a review of developments in protective devices. Chapters are devoted to the protection of generators, transformers, and high- and low-voltage lines.

PERFORMANCE and DESIGN of ALTERNATING CURRENT MACHINES. By M. G. Say and E. N. Pink. London and New York, Pitman Publishing Corporation, 1936. 552 pages, illustrated, 9x6 in., cloth, $6.00. Limited to the principal types of a-c machines; the transformer, the 3-phase induction motor, and the synchronous motor and generator. Outlines the theory of each, and discusses details of performance, control, testing, construction, and design.

MANAGING for PROFIT. By C. E. Knoeppel with the collaboration of E. G. Seybold. New York and London, McGraw-Hill Book Company, 1937. 343 pages, illustrated, 9x6 in., cloth, $3.50. Discusses working methods for profit planning and control and describes recently developed aids to management in the way of profit-making tools and methods.

INDEX to ASTM STANDARDS and TENTATIVE STANDARDS, January 1, 1937. Philadelphia, American Society for Testing Materials. 118 pages, 9x6 in., paper, gratis. Enables the user to ascertain whether the society has issued standard or tentative standards, test methods, or definitions upon any engineering material or subject, and to locate the volume in which the latest information is found.

ELEMENTS of APPLIED ELECTRICITY. 4 volumes. By B. C. Chatterjee. 2 edition. Benares, India, Shiva Narayan Chatterjee, 1 Laksha Road, 1931–1936. 8x5 in., cloth. Volume 1, 412 pages; volume 2, 736 pages; volumes 3–4, 1142 pages, apply. Presents a course in practical engineering intended primarily for students.

HISTORY of the DISCOVERY of PHOTOGRAPHY. By E. Potonniée, translated by E. Epstean. New York, Tennant and Ward, 1936. 272 pages, 10x6 in., cloth, $8.00. Affords an account of the origin of photography and of its development to the end of the Daguerrean period, about 1651.

THEORETICAL ASTROPHYSICS, Atomic Theory and the Analysis of Stellar Atmospheres and Envelopes. By S. Rosseland. Oxford, England, Clarendon Press; New York, Oxford University Press, 1936. 355 pages, illustrated, 10x6 in., cloth, $8.00. Presents a mathematical and physical picture of the constitutions of stellar atmospheres, gaseous nebular and inter-stellar clouds projected to atomic physics as a background.

Introduction to PHYSICAL OPTICS. By J. K. Robertson. 2 editions. New York, D. Van Nostrand Company, 1935. 471 pages, illustrated, 9x6 in., cloth, $4.00. Aims to provide a comprehensive introduction to the subject.

MEN, MONEY, and MOLECULES. By W. Haynes. Garden City, N. Y., Doubleday, Doran and Company, 1936. 214 pages, illustrated, 8x5 in., leather, $1.50. An informal history of the American chemical industry, intended for the general reader.

Deutsches Museum Abhandlungen und Berichte, Jg. 8, Heft. 1. GRÖSZE und MASSE der MOLEKÜLE und ATOME. By E. Rüchardt. Berlin, VDI-Verlag, 1936, 27 pages, illustrated, 8x6 in., paper, 0.90 rm. A brief account of the methods used for investigating the size and mass of molecules and atoms.

74. VDI-HAUPTVERSAMMLUNG DARMSTADT 1936 und 80-Jahrfeier des Vereines Deutscher Ingenieure. FACHVORTRAGE. Berlin, VDI-Verlag, 1936. 406 pages, illustrated, 12x8 in., paper, 6 rm. Contains papers presented at the annual meeting of the Verein Deutscher Ingenieure. Special attention is given to problems connected with national resources in food, raw materials, and power.

PHOTOGRAPHY. By C. E. K. Mees. New York, Macmillan Company, 1937. 226 pages, illustrated, 9x6 in., cloth, $3.00. A review of the whole subject of photography. Based upon a series of Christmas lectures at the Royal Institution, London; simple and popular in style.

ART and the MACHINE, an Account of Industrial Design in 20th-Century America. By S. Cheney and M. C. Cheney. New York, McGraw-Hill Book Company (Whittlesey House), 1936. 307 pages, illustrated, 10x7 in., cloth, $3.75. Discusses the new field of "industrial design." Traces the development of this blending experiment through the last few decades.

DEUTSCHES MUSEUM. Abhandlungen und Berichte, Jg. 6, Heft 5, 1936. ENTWICKLUNG der KINOTECHNIK. By R. Thun. Berlin, VDI-Verlag, pages 111–138, illustrated, 8x6 in., paper, 0.90 rm. Gives a brief, popular outline of the development of moving pictures.

EVERY DAY BUT SUNDAY, the Romantic Age of New England Industry. By J. F. Copeland. Brattleboro, Vt., Stephen Daye Press, 1936. 294 pages, illustrated, 9x6 in., cloth, $2.50. The story of Mansfield, Mass., carried to the end of the nineteenth century. Gives a picture of an early industrial community; of considerable historic interest.

HANDMAIDEN of the SCIENCES. By E. T. Bell. Baltimore, Williams and Wilkins Company, 1937. 216 pages, illustrated, 9x6 in., cloth, $2.00. Shows that mathematics, in one sense queen, is also the servant of the sciences. Explains and demonstrates the usefulness of such concepts as conic sections, fourth and higher dimensions, continuity and discreteness, chance and probability.

COMMUNICATION ENGINEERING. By W. L. Everitt. 2nd edition. New York and London, McGraw-Hill Book Company, 1937. 727 pages, illustrated, 9x6 in., cloth, $5.00. Treats the subject of communication systems as distinct from power systems. Consideration is given only to general and fundamental aspects of network theory and layout. Based on the assumption that the reader already has the necessary groundwork in principles of a-c and d-c systems, and leaves specific applications to be studied in the field. The chapters on complex quantities and medium- and high-requency measurements have been deleted.

DEUTSCHES MUSEUM, Abhandlungen und Berichte, Jg. 8, Heft 6, 1936. Die ENTWICKLUNG der FUNKENTELEGRAPHIE, by J. Zenneck. Berlin, VDI-Verlag, 1936. Pages 139–171, diagrams, 8x6 in., paper, 0.90 rm. Traces the fundamental ideas of wireless telegraphy and the principal steps in its development.

ELECTRICAL MEASUREMENTS, Precise Comparisons of Standards and Absolute Determinations of the Units. By H. L. Curtis. New York and London, McGraw-Hill Book Company, 1937. 302 pages, illustrated, 9x6 in., cloth $4.00. Deals with methods used in absolute measurements of electric units. The introductory chapters cover definitions and the history of electrical units. Discusses each absolute measurement determination given, but considers only the precise ones. Brief appendixes give the computation of elliptic integrals and the results of absolute determinations of electrical units in various countries.

ELEKTRISCHE MESSGERÄTE und MESSEINRICHTUNGEN. By A. Palm. Berlin, Julius Springer, 1937. 231 pages, illustrated, 9x6 in., cloth, 16.50 rm. A textbook for engineers and students, presenting the principles and construction of electrical measuring instruments and their practical applications.

ELEMENTS of ELECTRICITY. By W. H. Timbie. 3rd edition. New York, John Wiley and Sons, 1937. 569 pages, illustrated, 9x6 in., cloth, $3.00. Provides a brief treatment of a few fundamental ideas that a technical student must know well. Presents new material on electronics and vacuum tubes, and covers electrical measurements, batteries, and d-c and a-c machinery.

(The) IDENTITY THEORY. By B. Stevens. 2nd edition, revised and enlarged. Manchester, England, Sherratt & Hughes; New York, C. E. Stechert and Co., 1936. 243 + 16 pages, illustrated, 9x6 in., cloth, 7s. 6d. Presents a mathematical theory of space-time relations as applied to the universe. Text is divided into articles, each one presenting a single argument. The reader is assumed to have had mathematical training.

INDUSTRIAL ELECTRICITY and WIRING. By J. A. Moyer and J. F. Wostrel. 2nd edition. New York and London, McGraw-Hill Book Company, 1937. 502 pages, illustrated, 8x6 in., cloth, $2.75. Based on the latest regulations of the National Electrical Code. Covers fundamental theory and practical wiring information.

INSTRUMENT TRANSFORMERS. By B. Hague. London, Sir Isaac Pitman and Sons; New York, Pitman Publishing Corporation, 1936. 656 pages, illustrated, 9x6 in., cloth, $10.00. An extensive summary of papers and magazine articles, with the object of giving a general view of the complete field covering theory, construction, characteristic features, and testing of instrument transformers.

JONES ANTENNA HANDBOOK, 1937 edition. By F. C. Jones. San Francisco, Pacific Radio Publishing Company, 64 pages, illustrated, 9x6 in., paper, $0.50. Aims to provide practical guidance in the selection and construction of the best type of antenna for any specified purpose and location.

LEHRBUCH der HOCHFREQUENZTECHNIK. By F. Vilbig. Leipzig, Akademische Verlagsgesellschaft, 1937. 775 pages, illustrated, 9x6 in., cloth, 32.80 rm. Aims to provide a review of theory and current practice in the field of high-frequency engineering.

MARINE ELECTRIC POWER. By Q. B. Newman. New York, Simmons-Boardman Publishing Corporation, 1937. 159 pages, illustrated, 9x5 in., cloth, $2.00. A collection of material reprinted from *Marine Engineering* and *Shipping Review*, designed to present simply the basic principles underlying the electrical equipment used on ships. Intended primarily for those who have had little groundwork in physics and mathematics.

MATHEMATICAL RECREATIONS and ESSAYS. By W. W. R. Ball. 10th edition. London and New York, Macmillan and Company, 1931. 366 pages, illustrated, 8x5 in., cloth, $3.50. Covers arithmetical, geometrical, and mechanical problems, magic squares, and chess and playing-card recreations. Contains discussions of cryptographs, ciphers, and various famous calculating prodigies.

NATIONAL ASSOCIATION OF RAILROAD and UTILITIES COMMISSIONERS. PROCEEDINGS of 48th Annual Convention, held at Atlantic City, N. J., November 10 to 13, 1936. New York, State Law Reporting Co., 541 pages, tables, 9x6 in., cloth, $6.00. Contains the discussions on the topics set for this meeting. Includes uniform systems of accounts for gas and electric companies, the operation of the federal motor-carrier act, the regulation of electric utilities and of telephone companies, progress in public-utility regulation, and public-utility rates.

Industrial Notes

Large Generating Units on Order.—Orders have been placed by the Public Service Electric & Gas Co. (of N. J.) for a 50,000-kw turbine-generator and 2 high pressure steam boilers to be installed at the Essex generating station in Newark. This will increase the station's generating capacity from 193,000 kw to 243,000 kw. Boilers will be operated at 1,400 pounds pressure and at a temperature of 950 F, the highest combined temperature and pressure ever to be utilized in a generating station in this country. The turbine-generator will be built by the General Electric Co., and the steam boilers by the Babcock & Wilcox Co. Boilers will be equipped to burn either oil or pulverized coal and each will have a capacity of 605,000 pounds of steam per hour.

A third 110,000-kw turbine-generator unit will be added to the present River Rouge power plant of the Ford Motor Co. at Detroit, making the total installed capacity 350,000 kw. The new vertical compound turbine will be a duplicate of the second 110,000-kw unit, recently installed, for steam conditions of 1,200 pounds, 900 F. Hydrogen cooling is employed for the generators, which will be the 13th and 14th large turbine-driven units designed for hydrogen cooling to be built at the Schenectady works of the General Electric Co.

New Equipment for Pennsylvania Railroad.—After the April 14th directors' meeting of The Pennsylvania Railroad announcement was made that 2,800 new steel freight cars and the chassis for 11 new electric passenger locomotives of the heaviest and most powerful design will be constructed at the railroad's Altoona, Pa., works. The locomotives, known as the GG-1 type, will be assembled at Altoona with electrical parts supplied by the electrical manufacturing companies. The total cost of the equipment will be slightly in excess of $10,750,000. The new locomotives will supplement 58 others of the same type and 28 of a slightly different type already in use for high-speed passenger service in the electrified territory, and will provide part of the additional motive power required for the extension of the electrification now under way westward to Harrisburg, Pa.

Fansteel Annual Report.—The recently issued annual report of the Fansteel Metallurgical Corp., No. Chicago, Ill., shows an increase of slightly more than 50 per cent in sales over those for the corresponding period of 1936, despite a "sit-down" strike in February which interrupted all operations for nearly 2 weeks. The products of the company are based upon 4 metals—tantalum, columbium, tungsten and molybdenum having wide application in many industries, including the electrical manufacturing field. Tantalum is used in the production of electronic tubes and is the basis of the Balkite rectifiers and condensers. In addition to its use in lamp filaments tungsten has numerous uses in vacuum tubes, X-ray tubes, and neon signs. One of its principal uses is that for electrical contacts. The most common use for molybdenum is in electronic tubes and incandescent lamps. It is also used extensively in mercury switches and electrical contacts. Development of new metal alloys to be added to the company's line of products is in process and should be completed this year.

Manufacturers Report Record Orders.—General Electric Co. reports sales billed for the first quarter of 1937 as $73,412,420, compared with $51,423,071 for the same quarter last year, an increase of 43 per cent. Orders received during the first quarter of this year amounted to $105,747,030, compared with $59,569,879 for the same quarter of 1936, an increase of 78 per cent. This was the largest first quarter in the history of the Company.

Orders booked for the 3 months ending March 31, amounting to $74,242,584, by Westinghouse Electric & Mfg. Co., were the highest for any quarter on record and unfilled orders for the same period were the highest since 1923. The orders booked for the first 3 months of this year show an increase of 75 per cent over the same period in 1936.

General Electric Opens Exhibit.—An exhibit of electrical products for industry has been opened in the General Electric Building, 570 Lexington Ave., New York City. It brings together, in 7,000 square feet of floor space, a complete line of representative products of General Electric and its affiliates. Cable, distribution equipment, fractional-horsepower and integral motors, industrial control, industrial heating, lighting, meters and instruments, police radio, switchgear, transportation products, turbines and welding; the products of the incandescent lamp department, air conditioning department, and the construction material division and the plastics division of the appliance and merchandise department; and the products of the Trumbull Electric Co., General Electric X-Ray Corp., Warren Telechron Clock Co., General Electric Vapor Lamp Co., Bailey Meter Co., Locke Insulator Corp., and Carboloy Co., are on display. Much of the equipment is in operation.

Trade Literature

Insulators.—Catalog supplement and 2 articles, 5 pp. Outlines the theory of the design of O-B radio-interference-free pintype insulators, known as "Silentypes;" includes complete descriptions of the units available. Ohio Brass Co., 360 N. Main St., Mansfield, O.

Relays.—Folder. Describes a comprehensive line of relays, timing devices, thermostats, electric counters, melting pots, ladles, etc. Struthers Dunn, Inc., 139 North Juniper St., Philadelphia, Pa.

Recording Instruments.—Bulletin GEA-1061F, 32 pp. Describes strip-chart recording instruments; illustrates some of the more important improvements that have been made in the complete line of portable and switchboard type CD equipment. General Electric Co., Schenectady, N. Y.

Circuit Breakers.—Bulletin 33-226, 8 pp. Describes construction, operation and applications of type F-124 indoor oil circuit breakers for industrial and central station use. Rated at 50,000-kva interrupting capacity, manually and electrically operated, non-automatic and automatic, single throw. Westinghouse Electric & Mfg. Co. E. Pittsburgh, Pa.

Motor-Control Units.—Bulletin 67, 16 pp. Describes steel-clad motor-control units, each complete with disconnect switches, bus bars, contactor-type switching mechanisms, safety door-interlocks, meters and all the equipment necessary to meet the requirements of the individual application. The Electric Controller & Mfg. Co., Cleveland, O.

Magnetic Relays.—Bulletin 81, 8 pp. Lists more than 100 relays for intermediate duty (10–15 amperes) on d-c and a-c circuits for 2 and 3 wire control. Includes valuable coil and contact data, contact arrangements, enclosures, and illustrates relays assembled from standard parts for use on special applications. Ward Leonard Electric Co., Mount Vernon, N. Y.

Aerial Cables.—Bulletin GEA-2215, 52 pp. The book is intended mainly as a treatise on power cable and aims to facilitate selection of insulated cable for overhead transmission and distribution. Tables are presented showing the current carrying capacities of cables in air and also methods of calculating regulation. Some installation data is included in the bulletin. General Electric Co., Schenectady, N. Y.

Trolley Coaches.—Bulletin B2088, 32 pp., "The Modern Trolley Coach." Includes the essential data on typical electric-powered coaches of which there are at present over one thousand in use. The booklet traces the development and growth of this means of commutative transportation and studies its field of application. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Utility Distribution Supplies.—Catalog 37, 166 pp. A comprehensive listing of electrical distribution and transmission underground and street lighting equipment. Items included cover heavy and secondary cable racks, guy guards, anchors, clamps and clevises of many types, cross arms, insulator and pole top pins, brackets, glass and porcelain insulators, fuswitches, mast arms and accessories, etc. Utilities Service Co., Allentown, Pa.

Street Lighting Equipment.—Catalog Secs. 60–250,–260,–270,–275,–280,–300,–330,–340 and –450. Describe lighting standards and fittings. These sections include descriptions of cast iron standards, Hollowspun Granite (concrete) standards, Union Metal steel standards, top sections and casings for standards, brackets and equipment for poles, ornamental crooks; also luminaires for street lighting, street lighting glassware, and paragon and octagonal pendants. Westinghouse Electric & Mfg. Co., Lighting Division, Cleveland, O.